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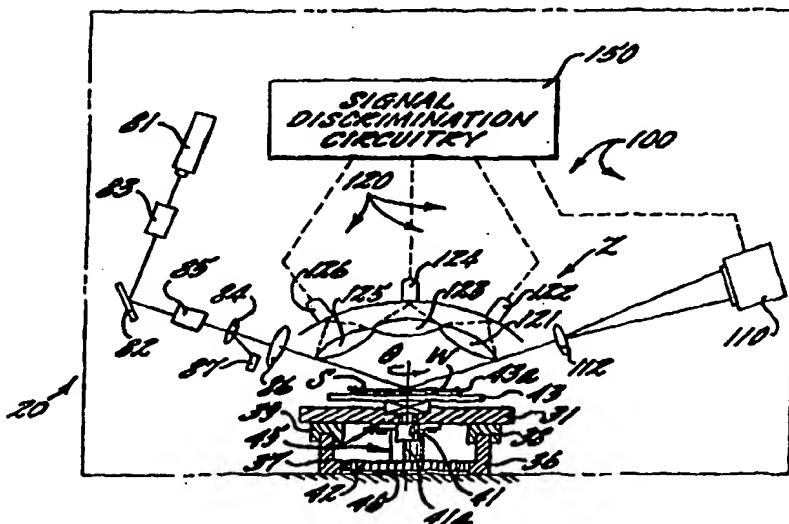
(57) Abstract

A surface inspection system (20) and method is provided which detects defects such as particles or pits on the surface of a workpiece (W), such as a silicon wafer, and also distinguishes between pit defects and particle defects. The surface inspection system (20) comprises an inspection station for receiving a workpiece and a scanner (80) positioned and arranged to scan a surface of the workpiece at the inspection station. The scanner (80) includes a light source (81) arranged to project a beam of P-polarized light and a deflector (85) positioned to scan the P-polarized light beam across the surface of the workpiece. The system further provides for detecting differences in the angular distribution of the light scattered from the workpiece and for distinguishing particle defects from pit defects based upon these differences.

WAFER INSPECTION SYSTEM FOR
DISTINGUISHING PITS AND PARTICLES

Field and Background of the Invention

The present invention relates to surface
5   inspection systems and methods and, more particularly,
to the inspection of articles or workpieces, such as
silicon wafers, to detect the presence of defects such
as particles or pits on the surface and to distinguish
therebetween.

10   Surface inspection systems are commonly used
for the inspection of articles or workpieces such as
silicon wafers to detect the presence of defects on the
wafer surface. When the inspection indicates a large
number of defects, the wafer may be sent back for
15   recleaning. If the defects are particles or other
debris on the wafer surface, the recleaning is
successful. However, if the defects are pits or "COPS"
(crystal originated pits) in the wafer surface, they
are not removed by recleaning. Because such surface
20   inspection systems fail to distinguish between pit
defects and particle defects, the wafer is typically
sent back for recleaning regardless of whether the
defects are pits or particles. Because these defects
may be pits, recleaning the wafer may result in nothing
25   more than a waste of time and resources. It would be
advantageous to be able to distinguish pits in the
surface of the wafer from particles located thereon.

Summary of the Invention

The present invention provides a surface
30   inspection system and method which not only detects
defects such as particles or pits on the surface of a
workpiece, such as a silicon wafer, but also
distinguishes between pit defects and particle defects.
This makes it possible to easily ascertain whether the

workpiece requires recleaning to remove particle defects, or whether other measures must be taken.

In a broad aspect, the surface inspection system comprises an inspection station for receiving a

5   workpiece and a scanner positioned and arranged to scan a surface of the workpiece at said inspection station. The scanner includes a light source arranged to project a beam of P-polarized light and a scanner positioned to scan the P-polarized light beam across the surface of

10 the workpiece. The system further provides for detecting differences in the angular distribution of the light scattered from the workpiece and for distinguishing particle defects from pit defects based upon these differences. The differences in the angular

15 distribution of the scattered light may, for example, be detected by comparing the amount of light scattered in a direction substantially perpendicular from the surface of the workpiece to the amount of light backscattered from the surface of the workpiece. The

20 detection of differences in the angular distribution of the scattered light may also, for example, involve identifying a dip in the intensity distribution of the scattered light.

The scanner preferably scans across the

25 surface of the workpiece along a relatively narrow scan path during rotational and translational travel of the workpiece. More specifically, the system preferably has a transporter arranged for transporting the workpiece along a material path and a rotator

30 associated with the transporter and arranged for rotating the workpiece during translational travel along the material path. The scanner is positioned and arranged for scanning a surface of a workpiece during rotational and translational travel along the material

35 path so that the entire surface of the workpiece is raster scanned in a spiral pattern. The scanner includes either a P-polarized light source or a light

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source coupled with a P-polarized filter positionally aligned with the light source.

A collector also is arranged for collecting light reflected and scattered from the surface of the workpiece during rotational and translational travel along the material path. The collector includes a dark channel detector positioned for detecting light which is scattered from the surface of a workpiece. The dark channel detector includes a plurality of collectors positioned and arranged for collecting light at different angles relative to the surface of the workpiece. Each collector includes a photodetector for generating electrical signals in response to the collected light. The electrical signals from photodetectors located at the different angles are compared to determine the differences in angular distribution of the scattered light.

The plurality of collectors preferably includes a forward channel collector arranged to collect light components scattered forwardly from the surface of the workpiece at a relatively small angle with respect to the specular reflection from the workpiece, a center channel collector positioned adjacent to the forward channel collector and arranged to collect light components scattered substantially normal from the surface of the workpiece at a relatively medium angle, and a back channel collector positioned adjacent to the center channel collector and arranged to collect light components scattered backwardly from the surface of the workpiece at a relatively large angle.

When the scanned light beam contacts a defect, such as a pit or a particle, light is scattered from the surface and is collected by the collectors. The intensity of the scattered light, and the time of its detection during the scan, provide information about the size and location of the defect on the

surface of the workpiece. Furthermore, the nature of
the defect, i.e. whether it is a pit or a particle, can
be ascertained by detecting differences in the angular
distribution of the light scattered from the workpiece.

5 For example, if the defect is a pit, the amount of
light scattered and detected by the center channel
collector is typically greater than that detected by
the back channel collector. Alternatively, if the
defect is a particle, the amount of the light detected

10 by the center channel collector is typically less than
that detected by the back channel collector and/or the
forward channel collector. The dark channel collector
system provides the surface inspection system of the
present invention with high sensitivity to more readily

15 identify, classify, and/or provide a topography of the
condition of the surface of an article or a workpiece,
including defects such as particles, pits and the like,
in and on the surface of a workpiece.

According to one specific embodiment of the

20 invention, a P-polarized light beam is directed along a
predetermined relatively narrow scan path and at a
relatively low angle of incidence with respect to the
surface of the workpiece. The method preferably also
includes imparting a rotational and translational

25 movement of the workpiece during the narrow scan so
that the narrow scan path traverses the entire surface
of the workpiece along a spiral path.

The surface inspection system and method of
the present invention advantageously distinguish pits

30 in the surface of the wafer from particles on the
surface of the wafer and therefore determine whether
cleaning or some other course of action, e.g., altering
the conditions of manufacture and storage, can be used
to cure the defects. In addition, the surface

35 inspection system and method provide high spatial
resolution, a small field of view at the object plane
which, in turn, provides improved edge detection

performance, improved repeatability in the inspection process and reduces interference signals caused by scatter from air molecules.

Brief Description Of The Drawings

5   Other advantages will appear as the description proceeds when taken in connection with the accompanying drawings, in which:

        Figure 1 is a perspective view of a surface inspection system according to the present invention.

10   Figure 2 illustrates a transporter of a surface inspection system according to the present invention arranged for rotatively and translationally transporting a workpiece, such as a wafer, along a material path.

15   Figure 3 schematically illustrates a side elevational view of a surface inspection system according to the present invention.

        Figure 3A is a fragmentary view of a light channel detector of a surface inspection system 20 according to the present invention.

        Figure 4 schematically illustrates a side elevational view of an optical scanning system of a surface inspection system according to the present invention.

25   Figure 5 schematically illustrates rotational and translational travel of a wafer through an inspection area according to the present invention.

        Figure 6 schematically illustrates a collector of a surface inspection system having 30 segmented optics for collecting light scattered from a surface of a wafer according to the present invention.

        Figure 7 schematically illustrates a system controller of a surface inspection system according to the present invention.

35   Figure 8 illustrates a comparison between using S-polarized and P-polarized light at normal and

non-normal angles of incidence to distinguish pits and particles in and on the surface of a wafer.

Figure 9 illustrates the use of P-polarized light at a non-normal angle of incidence in detecting 5 pits and several types of particles in and on the surface of a wafer.

Figure 10 illustrates a comparison between using P-polarized and S-polarized light in detecting a particle on the surface of a wafer and provides both 10 experimental and modeled results.

Figure 11 illustrates the use of P-polarized light at a non-normal angle of incidence in detecting scattered light for pits of various diameters in the surface of a wafer.

15   Figure 12 illustrates the use of P-polarized light in detecting pits of various diameters in a wafer.

Figure 13 illustrates the angular distribution pattern of relative small COPS and 20 particles using P-polarized light at a non-normal angle of incidence.

Figure 14 is an illustration similar to Figure 13 showing the angular distribution pattern of medium size COPS and particles.

25   Figure 15 is an illustration similar to Figure 13 showing the angular distribution pattern of larger size COPS and particles.

Figure 16 is a flowchart illustrating the application of an algorithm for distinguishing between 30 COPS and particles.

Figures 17 and 18 are graphs illustrating how the constants for the algorithm of Figure 16 may be derived.

Figure 19 is a particle map of a clean wafer.
35   Figure 20 is a COP map of a clean wafer.

Figure 21 is a particle map of the wafer of Figure 19 after particle defects of known size have been deposited thereon.

Figure 22 is a COP map of the wafer of Figure
5   21 with the particle deposition present, but not detected as COP defects.

Description of Illustrated Embodiment

The present invention will be described more fully hereinafter with reference to the accompanying
10 drawings in which specific embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the illustrated embodiments set forth herein; rather, these illustrated embodiments are
15 provided so that this disclosure will be thorough and complete and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

Figure 1 is a perspective view of a surface
20 inspection system 20 for detecting defects such as particles, pits and the like on a surface of a workpiece W or article, such as a silicon wafer. Portions of the system 20 are broken away for purposes of clarity and shown by phantom lines to illustrate
25 various elements of the surface inspection system 20. The surface inspection system 20 is suitably used for inspecting the surface of unpatterned wafers W, both with and without deposited films. The system 20 preferably includes means for translationally
30 transporting a workpiece W along a material path P, means associated with the translational transporting means for rotating the workpiece W as it travels along the material path P, means for scanning the surface S of the workpiece W during rotative and translational
35 travel along the material path P, and means for

collecting light reflected and scattered from the
surface S of the workpiece W.

As illustrated in Figure 1, the surface
inspection system 20 is arranged as a workstation

5 including a worktable 21. Positioned on the worktable
21 is a generally closed and substantially light proof
housing 22, a video display 23, a keyboard 25, and a
mouse 26. A cabinet 27 is suspended from the worktable
for carrying a system controller 50. Adjacent the

10 cabinet 27 is a shelf unit 28 for carrying a printer 29
and associated printing paper 29a. The housing 22 has
been partially broken away to better illustrate the
inspecting arrangement of the present invention. The
inspection of the wafer W preferably is conducted in an

15 inspection zone Z on an inspection table 31. A robotic
wafer handling device 32 is located adjacent the
inspection station 20 to load and unload wafers W from
a cassette 33 onto the table 31. The cassette 33 holds
a number of wafers W and is loaded into the cabinet 27

20 through a door (not shown). The handling of the wafers
W inside the housing 22 is done automatically without
contact by human hands to avoid contamination or
smudges.

As best illustrated in Figures 1-3, the

25 surface inspection system 20 preferably includes means
for translationally transporting a workpiece W along a
material path P. The means for transporting a
workpiece W is illustrated as a transporter 40 arranged
to translationally transport a workpiece W along a

30 material path P and preferably through an inspection
zone or area Z. The translational transporter 40, as
illustrated, preferably includes a gear 42, a motor 41
including a shaft 41a arranged for rotating the gear
42, and guides 36, 37 having teeth formed integral

35 therewith. The motor 41 and gear 42 mounted on the
motor shaft 41a form a chuck for the system 50. The
motor 41 of the chuck is preferably mounted to a stage

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member 43 having a plurality of flanges 43a extending
upwardly therefrom which receives the workpiece W,
i.e., silicon wafer, thereon along edges of the
workpiece W as illustrated.   This mounting technique
5   for the workpiece W reduces smudges or other surface
problems which may be associated with positioning the
lower surface of the workpiece so as to abuttingly
contact an upper surface of the stage member 43.   The
stage member 43 preferably is translationally
10   transported along stage guide members 38, 39 secured to
an underside thereof.   Other translational and/or
rotating means such as a piston and cylinder
configuration mounted to the stage member and a motor
for rotating the stage member as understood by those
15   skilled in the art may also be used according to the
invention.

        Also, means for rotating a workpiece W,
illustrated as a rotator 45, is associated with the
transporter 40 and arranged to rotate a workpiece W
20   during translational travel along the material path P.
The rotator 45 as illustrated preferably includes a
motor 46 mounted to an underside of the stage member
for providing rotation of the wafer mounted thereon at
a predetermined speed.   The transporter 40 and the
25   rotator 45 preferably are synchronized and arranged
with a scanner 80 so as to form a spiral-shaped narrow
angle scan (α) across the surfaces of the workpiece
during rotational and translational travel along the
material path P.

30   As illustrated in Figures 1 and 3-5, a
scanner 80 is positioned and arranged to scan a
surfaces of a workpiece W during rotational and
translational travel along the material path P.   It
will also be understood, however, by those skilled in
35   the art that the scanner 80 may be arranged for
rotational and/or translational movement while the
workpiece W is stationary, or translationally or

rotatively moved. In addition, other material paths P
may be used, e.g., neither the workpiece W nor the
scanner 80 may be translationally moved and the
workpiece tested in only a rotational path.

5   Accordingly, the present invention includes a P-
polarized light source 81 or a light source coupled
with a P-polarized filter positionally aligned with the
light source to generate a P-polarized light beam B
therefrom, means for receiving the light source and
10   scanning a surface S of a workpiece W, i.e., a mirror
82, lenses 84, 86, deflector 85, and means for
imparting a rotational and translational scan of the
workpiece W, i.e., the transporter 40 and the rotator
45.

15   The scanner 80 preferably includes a light
source 81, i.e., laser, arranged to either generate a
P-polarized light beam B therefrom or coupled with a P-
polarized filter positionally aligned with the light
source. The P-polarized light preferably has a spot
20   size which includes a full width, half-maximum of less
than 0.1 millimeters. The scanner also includes means
positioned to receive the light beam B and arranged for
scanning the light beam B along a relatively narrow
scan path (α) across a surface S of the workpiece W as
25   the workpiece W rotationally and translationally
travels along the material path P. The light source 81
is preferably a visible-light laser with a relatively
short wavelength, such as Argon-Ion or solid state, as
understood by those skilled in the art. The laser 81
30   is also preferably the combination of a laser with
external optics as understood by those skilled in the
art. The laser 81 preferably has a beam diameter of
about 0.6 millimeters ("mm").

               The scanning means preferably includes a
35   deflector 85, as illustrated, positioned to receive the
light beam B and arranged to deflect the light beam B
along a relatively narrow scan path (α). The deflector

85 is preferably an acousto-optical (AO) deflector as illustrated (or a mechanical deflector), and the relatively narrow scan path (α) is preferably no greater than 0.1 radians and, more particularly, in the

5   range of 0.025-0.040 radians. The scan path α preferably directionally corresponds to the path P of translational travel and, as best illustrated in Figure 4, preferably is in a generally parallel direction therewith as illustrated by the arrows. The deflection

10 is accomplished by exciting a crystal with high frequency sound waves, for example, which interact with the incident light wave in such a way to shift the light beam B and thereby change the angle of propagation. It will be understood that various

15 frequencies of the crystal will responsively cause the light passing therethrough to be deflected at correspondingly various angles of propagation. If the frequency of the sound waves is swept in a sawtooth pattern, the laser beam B is scanned through an angle

20 (α) proportional to the frequency. The AO deflector 85 preferably provides a constant scanning speed which, in turn, provides a consistent or a predetermined time response for particles or defects detected from an article surface. Although the present invention is

25 described with reference to an AO deflector 85, other means for providing narrow angle scans as understood by those skilled in the art, such as a galvanometer, a piezoelectric scanner, a resonant scanner, a rotating mirror, a scanning head, other electronic scanners, or

30 the like, may also be used according to the present invention.

Also, a beam expander 82 is preferably positioned between the laser source 81 and the deflector 85 to expand the light beam B prior to

35 entering the acousto-optical deflector 85. The beam expander 82 preferably provides means for more fully

filling the active aperture of the deflector 85 to best utilize the scan angle of the deflector 85.

The scanner 80 also preferably includes means positionally aligned with the deflector 85 and arranged
5   for directing the light beam from the narrow scan path (α) toward a surface S of a workpiece W at a relatively low angle of incidence (θ_i) (relative to the workpiece surface) as the workpiece W rotatively and translationally travels along the material path P.
10   Although a low angle of incidence (θ_i) is preferred, the angle of incidence (θ_i) may be any angle other than normal to the workpiece W to provide the advantages of the present invention.   The angle of incidence is preferably greater than 45 degrees from normal to the
15   article surface, i.e., less than 45 degrees from the surface of the workpiece W and, more particularly, is preferably in the range of 65-85 degrees from normal to the article surface.

The directing means is illustrated as a
20   mirror 82 and a plurality of optical lenses 84, 86 arranged to direct the light beam B from the laser 81 toward the surface S of the workpiece W to be inspected.   As the light beam B travels from the AO deflector 85, the beam B passes through a cylindrical
25   lens 84 which preferably angularly orients the light beam B for a linear scan of the surface of the article during translational and rotational movement of the article through the inspection zone.   A stop member 87 is positionally aligned with the cylindrical lens 84
30   positioned closely adjacent the AO deflector 85 to stop the relatively small portion of light which is not linearly oriented for the scan of the surface of the workpiece W.   The optical lens 86 positioned after the cylindrical lens 84 is a focusing or f-theta lens, as
35   understood by those skilled in the art, arranged for focusing the light beam on the surface of the workpiece W.

The scanner 80 according to the present
invention preferably scans the beam of light B in a
radial direction with rotating motion and linear,
lateral, or translational motion (Y) to implement a
5   spiral scan pattern as best illustrated in Figure 3.
Nevertheless, any other material path P for the
workpiece W may also be used to provide the advantages
of the invention.

As best illustrated in Figures 1, 3, 3A, and
10   6-7, means for collecting light from the surface of a
workpiece is preferably a collector 100 having a light
channel detector 110 arranged for detecting light
specularly reflected from the surface S of a workpiece
W and a dark channel detector 120 positioned adjacent
15   the light channel detector 110 for detecting light
scattered from the surface S of a workpiece W. The
light channel detector 110 may be a PMT or a
photodiode, but preferably, as understood by those
skilled in the art, is a quadrant-cell device, i.e.,
20   detector, arranged for X-Y coordinate positioning
detection so that deviation in the path of reflected
light, i.e., during detection of a defect or particle,
may be determined. Such quadrant-cell detectors are
manufactured by Advanced Photonix, Inc., formerly
25   Silicon Detector Corp., of Camarillo, California.
Although a particular configuration is illustrated, it
will be understood that various other rectangular or
multiple cell, i.e., bi-cell, configurations may also
be used according to the present invention.

30   The dark channel detector 120 preferably
includes a plurality of collectors 121, 123, 125
positioned closely adjacent each other and arranged for
collecting components of the scattered light at
different respective predetermined angles from the
35   surface S of the workpiece W. The plurality of
collectors 121, 123, 125 of the dark channel detector
120 form segmented optics having at least two

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collectors positioned adjacent each other. The
plurality of collectors 121, 123, 125 as illustrated
will be understood by those skilled in the art to be
compound lenses, and other lens arrangements may also
5   be used according to the present invention. The
plurality of collectors 121, 123, 125 respectively
include a forward channel collector 121 arranged to
collect light components scattered forwardly from the
surface S of the workpiece W at a relatively small
10 angle a, a center channel collector 123 positioned
closely adjacent the forward channel collector 121 and
arranged to collect light components scattered
substantially normal from the surface S of the
workpiece W at a relatively medium angle b, and a back
15 channel collector 125 positioned closely adjacent the
center channel collector 123 and arranged to collect
light components scattered backwardly from the surface
S of the workpiece W at a relatively large angle c.
The dark channel detector 120 further includes a
20 forward channel detector 122, a center channel detector
124, and a back channel detector 126 each respectively
positioned in optical communication with a
corresponding collector 121, 123, 125, and means
electrically connected to the forward, center and back
25 channel detectors 122, 124, 126 and responsive to
electrical signals from said detectors for determining
the presence of a particle on the surface S of a
workpiece W. The determining means of the collector is
preferably electronic signal discrimination circuitry
30 150, such as illustrated (see Figures 3 and 7) and
understood by those skilled in the art, which receives
signals representative of collected light from the
light channel detector 110 and the dark channel
detector 120.

35   As best illustrated in Figures 1, 3, and 6,
the relative respective angles a, b, c of the plurality
of collectors 121, 123, 125 are preferably determined

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with respect to the angle of reflection (θ_r) of light
from the surface S of the workpiece W and with respect
to forward a, backward c, and substantially normal b
light component scattering which occurs relative to the
5   angle of incidence θ_i of the scan. For example, if the
angle of incidence θ_i is relatively low with respect to
the surface plane (high with respect to normal), e.g.,
15° from horizontal or -75° from normal, then the
forward scattering or small angle a is preferably about
10   +22° to +67°, the substantially normal scattering or
medium angle is about -25° to +20°, and the backward
scattering or large angle is about -72° to -27°. In
addition, the advantages of the present invention have
been realized, for example, where the angle of
15   incidence θ_i is 25° from horizontal or -65° from normal
with P-polarized visible light having a wavelength of
488 nm, the back channel collector is centered at -38°,
and the center channel collector is centered at +10°.
When a particle or defect is detected, for example, the
20   forward channel collector 121 is positioned to receive
and collect forward scattering a, the center channel
collector 123 is positioned to receive and collect
substantially normal scattering b, and the back channel
collector 125 is positioned to receive and collect back
25   scattering c from the surface of the workpiece with
respect to the detected particle or defect, or the
like. In the direction generally perpendicular to the
plane of incidence, approximately 73° of total angle is
captured in the above example. This is about 0.64
30   steridians of solid angle per segment or a total of
about 1.92 steridians which is a substantial
improvement over previous known detectors.

        As best illustrated in the perspective view
of Figure 1 and the schematic view of Figure 7, the
35   surface inspection system 20 preferably is computer
controlled. The system controller 50 operates the
inspection system 20 under the supervision and

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direction of a human operator, stores and retrieves data generated by the system 20, and performs data analysis preferably responsive to predetermined commands. The scanner assembly portion 90 illustrated
5   cooperates with the scanner 80 and includes a chuck detector 91 which transmits a position to a servo-amplifier 91. The relative position of the article being inspected is communicated to the system 50 via motors 41, 46 and encoders 93 mounted thereto. The
10   position data is transmitted to the AO scan control 73 which preferably forms a portion of the system electronics chassis 70 and which responsively drives the AO deflector 85 via a AO scan driver 95.

        The system electronics chassis 70 includes a
15   system power supply 71 and receives signals from the dark channel detectors 120 and the light channel detector 110 respectively representative of the scattered and the specularly reflected light. As understood by those skilled in the art, these data
20   signals are conventionally electrically communicated in an analog format to analog front end electronics 75 and are converted to digital format by digital front end electronics 74 or the like. The digital front end electronics 74 also cooperates with the AO scan control
25   73, the system bus interface 72, and the differential interface 69, i.e., differential bus, of the personal computer ("PC") chassis 60. The system bus interface 72 also communicates with a laser power supply 51 of the surface inspection system 50.
30   The PC chassis 60 includes a PC power supply 61 arranged for supplying power to the PC. The PC chassis 60 also has a motion controller 64 which responsively communicates with the servo amplifier 92 of the scanner assembly 90 and a system control
35   computer 65, i.e., microprocessor, or controller. The system control computer 65 preferably electrically communicates with a wafer handler 52 for responsively

sending and receiving predetermined command signals for mounting and handling the article or wafer being inspected as set forth above. The system control computer 65 also preferably communicates with a hard

5   disk drive 68, a display adapter 67 arranged to communicate with the display, and an ethernet interface 66 arranged for network or other system 50 communication. An image processor 64 electrically communicates with the differential interface 69 and the

10 system control computer 65 for processing the image of the surface of the inspected article and/or defects, flaws, undulations, or particles thereon. The surface inspection system 50 as illustrated in Figure 7, and as understood by those skilled in the art, preferably is

15 formed of a combination of software and hardware which forms these various components, or combinations thereof, of the system 50.

As illustrated in Figures 1-7, methods of inspecting a surface S of an article or workpiece W for

20 defects are also provided according to the present invention. A method of inspecting a surface S of a workpiece W preferably includes rotatively and translationally transporting a workpiece W along a material path P and scanning a relatively narrow scan

25 path α of light across a surface of the workpiece W as the workpiece W travels along the material path P. The step of rotatively and translationally transporting a workpiece along a material path preferably is synchronized with the step of scanning a surface of the

30 workpiece so as to impart a substantially spiral-shaped scan of the surface of the workpiece. Light specularly reflected from and light scattered from the surface S of the workpiece W preferably are separately collected. The light which is scattered from the workpiece surface

35 is collected as separate light components at different angles. For example, light components scattered substantially normal from the surface S of the

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workpiece W and light components scattered backwardly
from the surface S of the workpiece W are separately
collected and compared to thereby ascertain differences
in the angular distribution of the scattered light.

5   Light scattered from the surface S of the workpiece W
is separately collected by a plurality of collectors
121, 123, 125 at a plurality of predetermined
scattering angles a, b, c. Preferably, the collectors
are positioned to collect forwardly scattered light

10   components, backwardly scattered light components, and
light components scattered in a direction substantially
perpendicular to the surface of the workpiece. Light
detected by the various collectors signifies a defect
in or on the surface S of the workpiece W.

15   In order to determine whether the defect is a
particle defect or a pit, differences in the angular
distribution of the light scattered from the workpiece
are detected. This is achieved by comparing the amount
of light collected by one of the collectors to the

20   amount of light collected by one or more of the other
collectors. The light detected by the detectors 122,
124 and 126, particularly the center channel detector
124 and the back channel detector 126 can be used to
distinguish particles located on the workpiece surface

25   from pits located in the workpiece surface when P-
polarized light is used in the scanner. Specifically,
when the defect is a pit in the workpiece surface, P-
polarized light scattered from the workpiece surface
forms a pattern in which the amount of light scattered

30   to the center channel collector 124 is greater than the
amount of light scattered to the back channel collector
126. This has been found to be particularly the case
with small pits, i.e., pits having a diameter of no
more than about 300 nm. In contrast, when the defect

35   is a particle on the workpiece surface, P-polarized
light scattered from the wafer surface forms a pattern
in which the amount of light scattered to the center

channel collector 124 is less than the light scattered
to the back channel collector 126. Figures 8-15 show
examples of the scattered light distributions for pits
and particles of various sizes when P-polarized light
5   is used. Figure 8 is a comparison between scatter
diagrams for 90 nm tungsten particles on the surface of
the workpiece and 180 nm pits in the surface of the
workpiece. As seen from the two scatter diagrams on
the left side of Figure 8, the use of either S-
10 polarized light and the use of a normal or
perpendicular angle of incidence, i.e., $\theta_i = 0°$, with
either S or P-polarized light does not provide an
effective method of distinguishing the particles from
the pits in the surface of the workpiece. The angular
15 distribution of the light scattered from the workpiece
is substantially similar for pit defects and for
particle defects. Likewise, as seen from the scatter
diagram in the upper right quadrant, when S-polarized
light is used at a non-normal angle of incidence, for
20 example $\theta_i = -70°$, there is relatively little difference
in the shape of the scatter curves for pits and for
particles. However, when P-polarized light is used, as
seen from the diagram in the lower right quadrant, the
particles scatter light in such a way that a dip is
25 detected in the region approximately perpendicular to
the workpiece surface. The pits create a distinctly
different angular distribution pattern, by which pits
can be distinguished from particles.

Figure 9 illustrates the angular distribution
30 patterns obtained from various particle materials.
When P-polarized light is used at an angle of
incidence, $\theta_i = -70°$, the particles may be distinguished
by a characteristic dip in the region approximate the
angle normal the workpiece surface (0°) thus allowing
35 the presence of particles on the surface of the
workpiece to be distinguished from the presence of pits
within the workpiece. Specifically, the 120 nm psl

particles, the 90 nm silicon particles, the 80 nm
tungsten particles, and the 75 nm aluminum particles
all exhibit a characteristic dip in the vicinity of the
direction normal or perpendicular to the surface of the
5   workpiece (0°). The specific minimum point varies for
each particle, but all are generally within a region
covering ± about 25° from the 0 or perpendicular
direction. The scattering pattern from the pit does
not exhibit a dip.

10   Figure 10 compares the angular distributions
for modeled results and experimental results using a
0.1 micron psl sphere with a laser beam at a wavelength
of 488 nm and a -75° angle of incidence using both P-
polarized light and S-polarized light. As shown, the
15   P-polarized light produces a characteristic dip in the
vicinity of 0°. No such dip occurs using S-polarized
light.

             Figure 11 illustrates modeled scatter for
pits of various diameters. As shown in Figure 11, when
20   P-polarized light is used at an angle of incidence, θ_i =
-70°, the amount of backwardly scattered light is
greater than the amount of forwardly scattered light
for small pits. This is particularly the case where
the diameter of the pit is no more than about 300 nm.

25   Figure 12 illustrates the angular
distribution of light scattered by larger pits, i.e.,
pits having a diameter of more than about 430 nm,
located in the surface of the workpiece.

             Figures 13, 14 and 15 illustrate
30   representative angular distribution patterns for small
COPS, medium COPS and large COPS respectively, versus
particles using P-polarized light at an angle of
incidence of -70°. In Figure 13, it will be seen that
a 120 nm cup exhibits a convex shaped distribution
35   pattern, with the amount of light backscattered at
angles ranging from -20 to -60 being higher than the
light forwardly scattered at angles of +20 and above.

Particles of various compositions with sizes of 90 nm
and below all exhibit a characteristic concave
distribution pattern, with a "dip" in the vicinity of
0°. For the larger sized particles, e.g. 90 mn psl,
5   the intensity of forwardly scattered light is greater
than the backscattered light.

         As seen from Figure 14, the angular
distribution pattern for a somewhat larger 155 nm COP
is generally similar to the 120 nm cup of Figure 13,
10   with the amount of backscattered light at angles of
from -20 to -80 being greater than the amount of
forwardly scattered light. The smaller sized
particles, e.g. 91 nm and smaller consistently exhibit
a concave distribution pattern with a "dip" at or near
15   0°, and with the amount of forwardly scattered light
being greater than the amount of backscattered light.
The larger particles (120 nm psl) show a markedly
greater difference between the amount of forwardly
scattered light and backscattered light. This trend is
20   also seen in Figure 15 with particles as large as 200
nm.

         From these characteristic angular
distribution patterns, it is possible to distinguish
COPS from particles. In particular, if the ratio of
25   the intensity of the signal from the center channel
detector 124 to the signal from the back channel
detector 125 is less than a predetermined amount, the
defect may be classified as a particle. If the ratio
of the intensity of the center channel detector 124
30   signal to the forward channel 122 detector signal is
more than a predetermined amount, the defect may be
classified as a pit. Figure 16 illustrates one
suitable algorithm for analyzing the information from
the detectors to distinguish particles from COPS. If
35   the ratio of the center channel indicated size C to the
back channel indicated size B is less than the
predetermined constant, in this instance 1.14, then the

defect is classified as a particle. Stated otherwise,
a signal event B representing the back channel
indicated size and a signal event C representing the
center channel indicated size are directed to a
5   comparator where the value of C is compared to the
value of B times a predetermined constant, in this
instance 1.14. If C is not greater than 1.14 times B,
then the signal event is classified as a particle. If
C is greater than 1.14 times B, then C is compared to a
10   value F representing the forward channel indicated
size. If C is greater than a predetermined constant
(in this instance 1.36) times the value of F, then the
signal event is classified as a COP. If not, the event
is classified as a particle.

15   The application of this algorithm as applied
to COPS is graphically illustrated in Figure 17. The
application of this algorithm to particles, in this
instance aluminum particles, is graphically illustrated
in Figure 18. Figures 17 and 18 illustrate how modeled
20   data or experimental data for particles or COPS of
various sizes can be used to derive constants for use
in the type of algorithm shown in Figure 16. It should
be apparent to those of skill in the art from this
illustration that the present invention is not limited
25   to the particular algorithm described herein, and that
other approaches and other specific algorithms may be
used to process the data obtained from the various
detectors and to distinguish between pits and particles
in accordance with the present invention.

30   During the scanning of a wafer, as signal
events are thus classified into particle defects and
pit defects, the resulting data may be stored in memory
in a suitable format, such as a raster format, to
define a "map" of the particles or pits on the surface
35   of the wafer. In addition, the intensity values of the
signal events, representing the indicated sizes of the
particles or pits, may be stored to provide a histogram

illustrating the size classifications of the defects.
This information may be communicated to the user as a
visual representation of the wafer on a video display.
Figure 19, for example, illustrates a video display
5   which presents a particle map of a clean wafer,
together with a histogram showing the distribution of
particle sizes. Figure 20 shows a map of the COPS or
pits for the same wafer, and a size histogram for the
pits. Figures 21 and 22 illustrate the sensitivity and
10   selectivity of the apparatus and method of this
invention. The same wafer which was used to produce
the particle map of Figure 19 was "seeded" with
particle defects of known size in three regions on the
wafer. Figure 21 is a particle map of that wafer, and
15   the three regions of seeded particles are clearly
evident. Figure 22 is a COP map of that same wafer.
By comparing Figure 20 (before seeding) with Figure 22
(after seeding) it is evident that the COP map and the
histogram are substantially unaffected by the heavy
20   concentrations of seeded particles on the wafer.

         In the drawings and specification, there have
been disclosed typical preferred embodiments of the
invention, and, although specific terms are employed,
these terms are used in a descriptive sense only and
25   not for purposes of limitation. The invention has been
described in considerable detail with specific
reference to various illustrated embodiments. It will
be apparent, however, that various modifications and
changes can be made within the spirit and scope of the
30   invention as described in the foregoing specification
and defined in the appended claims.

THAT WHICH IS CLAIMED:

1.   A surface inspection system for distinguishing between particle defects and pit defects on a surface of a workpiece, the surface inspection
5 system comprising:

an inspection station for receiving a workpiece;

a scanner positioned and arranged to scan a surface of the workpiece at said inspection station,
10 said scanner including a light source arranged to project a beam of P-polarized light and means positioned to scan the P-polarized light beam across the surface of the workpiece; and

means for detecting differences in the
15 angular distribution of the light scattered from the workpiece and for distinguishing particle defects from pit defects based upon said differences.

2.   A surface inspection system as defined in Claim 1, wherein said means for detecting
20 differences in the angular distribution of the scattered light includes means for comparing the amount of light scattered in a direction substantially perpendicular from the surface of the workpiece to the amount of light backscattered from the surface of the
25 workpiece.

3.   A surface inspection system as defined in Claim 1, wherein said means for detecting differences in the angular distribution of the scattered light includes means for identifying a dip in
30 the intensity distribution of the scattered light.

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4. A surface inspection system as defined in Claim 1, wherein said means for detecting differences in the angular distribution of the scattered light comprises a plurality of collectors
5 positioned and arranged for collecting light at different angles relative to the surface of the workpiece, said collectors each including a photodetector for generating signals in response to the collected light, and means for comparing the signals
10 from photodetectors located at said different angles.

5. A surface inspection system as defined in Claim 4, wherein said plurality of collectors includes a first collector positioned and arranged to
15 collect light components scattered generally perpendicular from the surface of the workpiece, and a second collector positioned and arranged to collect light components scattered angularly from the surface of the workpiece.

20   6. A surface inspection system as defined in Claim 5, wherein said scanner is positioned and arranged to direct the light beam onto the surface of the workpiece at a predetermined angle of incidence other than perpendicular, and said second collector is
25 positioned and arranged to collect backscattered light components.

7. A surface inspection system as defined in Claim 6, wherein said plurality of collectors additionally includes a third collector positioned and
30 arranged to collect light components forwardly scattered from the surface of the workpiece.

8. A surface inspection system as defined in Claim 6, wherein said scanner is positioned and arranged to direct the light beam onto the surface of

the workpiece at an angle of incidence of at least -50°
from perpendicular to the workpiece surface.

        9.   A surface inspection system as defined
in Claim 5, wherein said first collector is arranged to
5   collect light components scattered over an angle of
approximately ±20° from perpendicular to the workpiece
surface.

        10.   A surface inspection system as defined
any one of claims 1 to 9, additionally including means
10   to form a first map identifying the locations of pit
defects on the workpiece surface and a second map
identifying the locations of particle defects on the
workpiece surface.

        11.   A surface inspection system as defined
15   in Claim 10, including a video display operatively
associated with said means to form said first and
second maps for displaying a visual representation of
said first and second maps.

        12.   A surface inspection system as defined
20   in claim 1 wherein said light source is arranged to
project a beam of P-polarized light at an angle of
incidence at least 50 degrees rearward of perpendicular
to the workpiece surface, and wherein said means for
detecting and distinguishing includes a detector
25   arranged for detecting light scattered from the surface
of a workpiece at said inspection station, said
detector including a center channel collector
positioned and arranged to collect light components
scattered substantially perpendicular from the surface
30   of the workpiece, and a back channel collector
positioned and arranged to collect light components
backscattered from the surface of the workpiece, said
collectors each including photodetectors for generating

electrical signals in response to the collected light; and

a comparator responsive to electrical signals from the photodetectors of said center channel
5 collector and said back channel collector for detecting differences in the angular distribution of the scattered P-polarized light from the workpiece.

13. A surface inspection system as defined in Claim 12, wherein said comparator includes a first
10 comparer for identifying a defect as a particle if the ratio of the intensity of the center channel photodetector signal to the back channel photodetector signal is less than a predetermined amount.

14. A surface inspection system as defined
15 in Claim 15, wherein said detector additionally includes a forward channel collector positioned and arranged to collect light components forwardly scattered from the surface of the workpiece, said forward channel collector including a photodetector for
20 generating an electrical signal in response to the collected light, and wherein said comparator includes a second comparer for identifying a defect as a pit if the ratio of the intensity of the center channel photodetector signal to the forward channel
25 photodetector signal is more than a predetermined amount.

15. A surface inspection method for distinguishing between particle defects and pit defects on a surface of a workpiece, said method comprising:
30   scanning a beam of P-polarized light across the surface of the workpiece;

collecting light scattered from the surface of the workpiece; and

detecting differences in the angular
distribution of the light scattered from the workpiece
and distinguishing particle defects from pit defects
based upon said differences.

5   16.   A method as defined by Claim 15, wherein
said step of detecting differences in the angular
distribution of the scattered light comprises comparing
the amount of light scattered in a direction generally
perpendicular from the surface of the workpiece to the
10 amount of light scattered backwardly from the surface
of the workpiece.

          17.   A method as defined by Claim 15, wherein
said step of detecting differences in the angular
distribution of the scattered light comprises
15 identifying a dip in the intensity distribution of the
scattered light.

          18.   A method as defined by Claim 15, wherein
said step of detecting differences in the angular
distribution of the scattered light includes comparing
20 the intensity of scattered light collected at various
angles relative to the surface of the workpiece.

          19.   A method as defined by Claim 18, wherein
said step of detecting differences in the angular
distribution of the scattered light includes comparing
25 the intensity of light components scattered
substantially perpendicular from the surface of the
workpiece to the intensity of the light components
scattered angularly from the surface of the workpiece.

          20.   A method as defined by any one of claims
30 15 to 19, additionally including forming a first map
identifying the locations of pit defects on the
workpiece surface.

21. A method as defined by Claim 20, including forming a second map identifying the locations of particle defects on the workpiece surface.

22. A method as defined in Claim 21,
5 including displaying said first and second maps on a video display.

23. A method as defined by Claim 19, wherein said step of scanning a beam across the surface of the workpiece comprises projecting the beam of light onto
10 the workpiece at an angle of incidence of at least 50 degrees from perpendicular to the workpiece.

24. A surface inspection method for distinguishing between particle defects and pit defects on a surface of a workpiece, said method comprising:
15 receiving a workpiece at an inspection station;
scanning a surface of a workpiece at the inspection station with a beam of P-polarized light at an angle of incidence of at least 50 degrees rearward
20 of perpendicular to the workpiece surface;
collecting light scattered from the surface of a workpiece at the inspection station with a first collector positioned and arranged to collect light components scattered generally perpendicular from the
25 surface of the workpiece, and with a second collector positioned and arranged to collect light components backscattered from the surface of the workpiece;
converting the collected light components from the first collector and the second collector into
30 respective electrical signals; and
analyzing the signals to distinguish particle defects from pit defects.

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25. A surface inspection method as defined in Claim 24, wherein said analyzing step comprises identifying a defect as a particle if the ratio of the intensity of the first collector signal to the second collector signal is less than a predetermined amount.

26. A surface inspection method as defined in Claim 25, wherein said collecting step additionally includes collecting light scattered from the surface of a workpiece at the inspection station with a third collector positioned and arranged to collect light components scattered forwardly from the surface of the workpiece and converting the collected light into an electrical signal, and wherein said analyzing step includes identifying a defect as a pit if the ratio of the intensity of the first collector signal to the third collector signal is more than a predetermined amount.

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Fig. 1.

Fig. 2.

Fig.3.

LASER

BEAM EXPANDER

ACOUSTO-OPTIC DEFLECTOR

Fig.4.

Fig.3a.

WAFER SURFACE (S)

=FIG.5.

WAFER
FLOW
(P)

W

S

LASER BEAM

θ

MEDIUM ANGLE
DARK CHANNEL
DETECTOR

LARGE ANGLE
DARK CHANNEL
DETECTOR

SMALL ANGLE
DARK CHANNEL
DETECTOR

120

124

125

123

126

122

121

130

112

b

a

c

θ_i

θ_r

θ

=FIG.6.

Fig. 7.

$\theta_i = 0°$

FIG. 8A

$\theta_i = -70°$

FIG. 8B

$\theta_i = 0°$

FIG. 8C

$\theta_i = -70°$
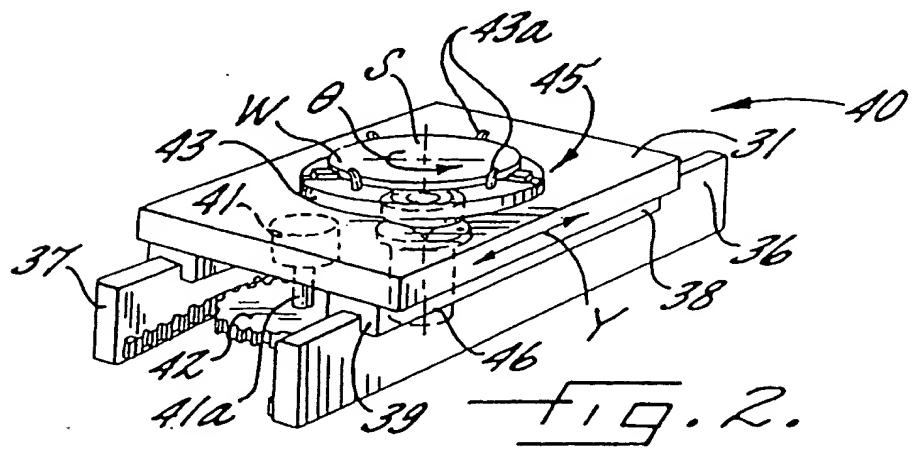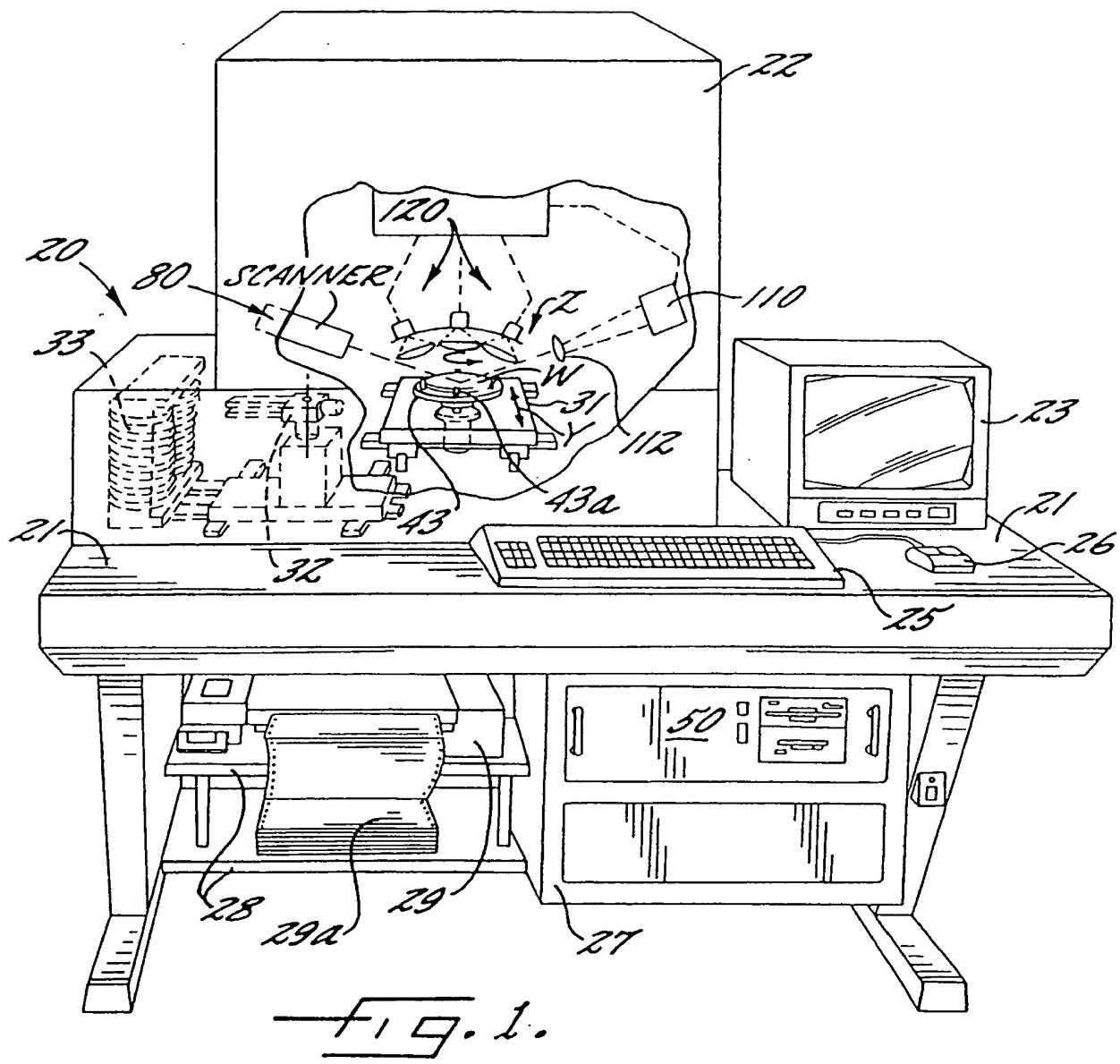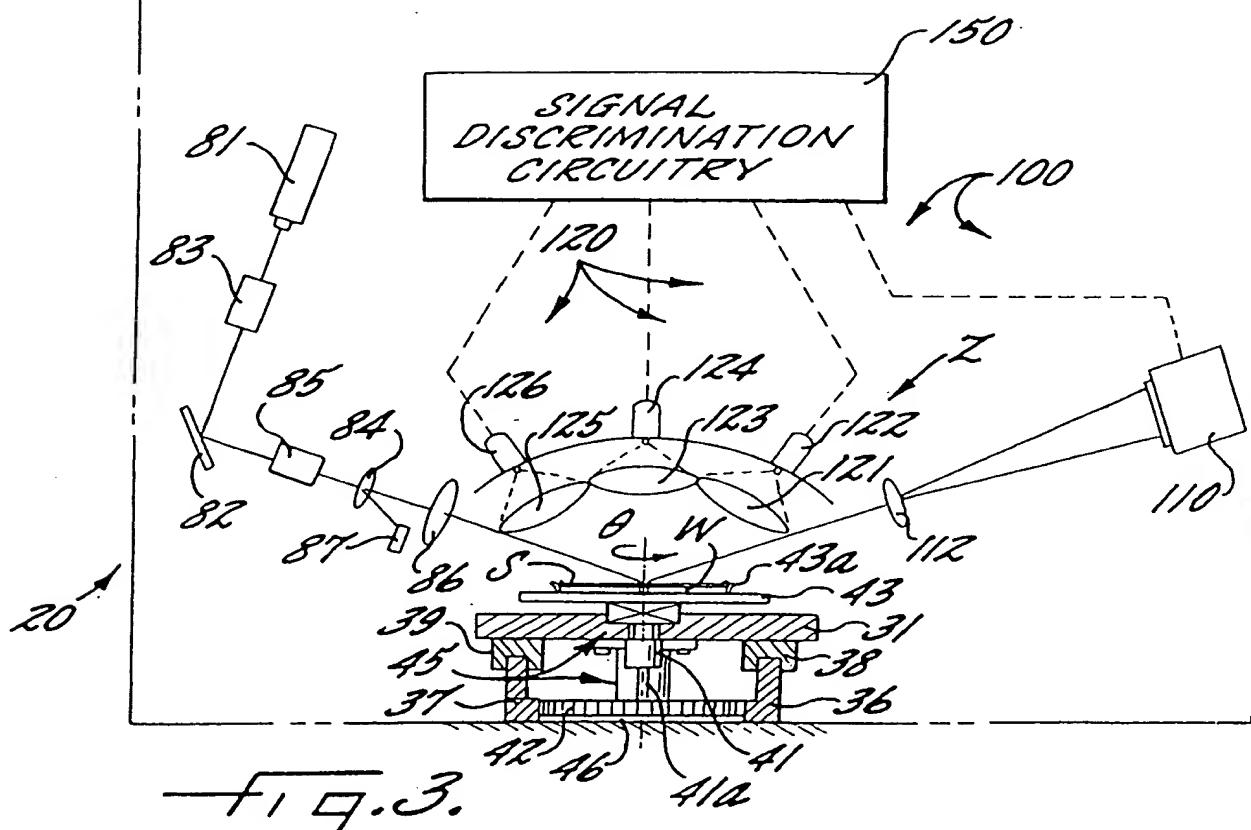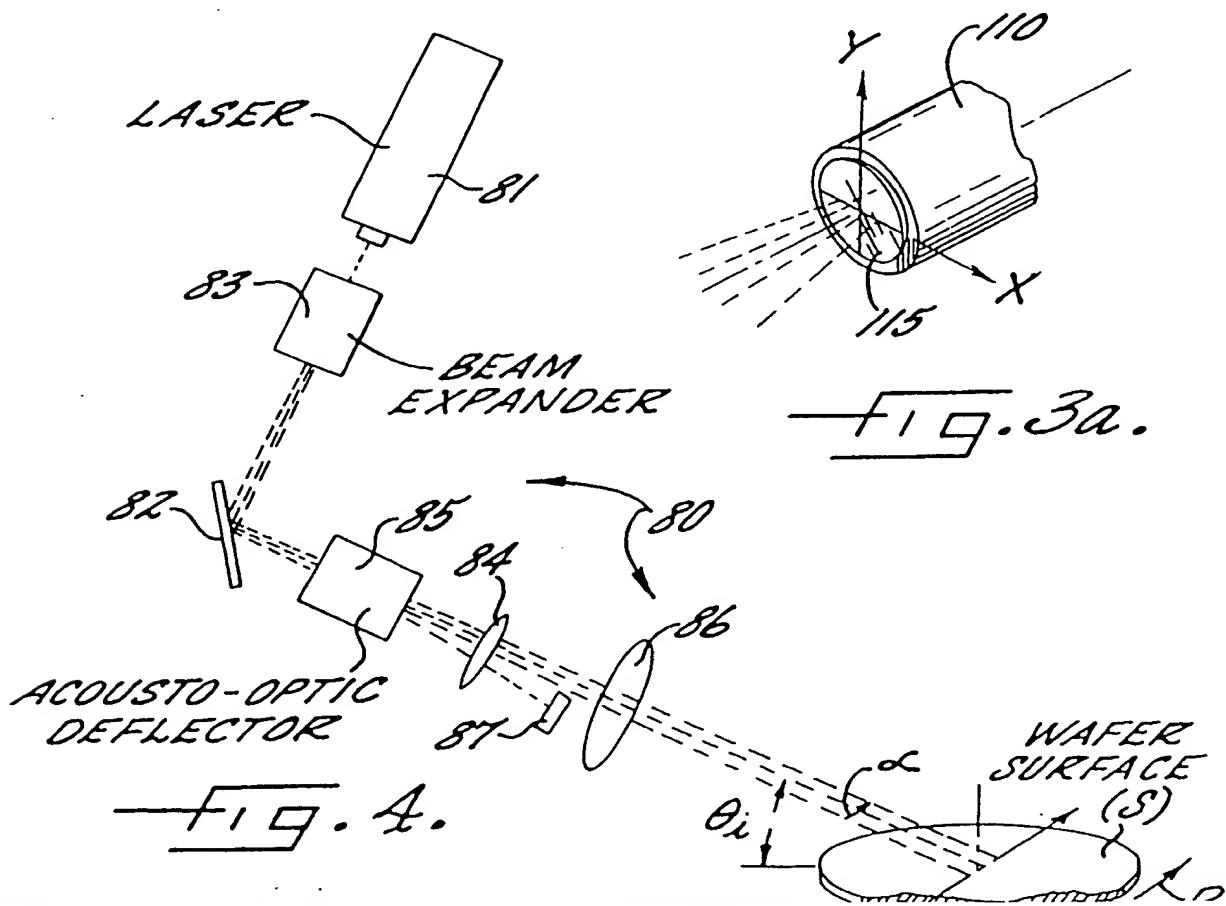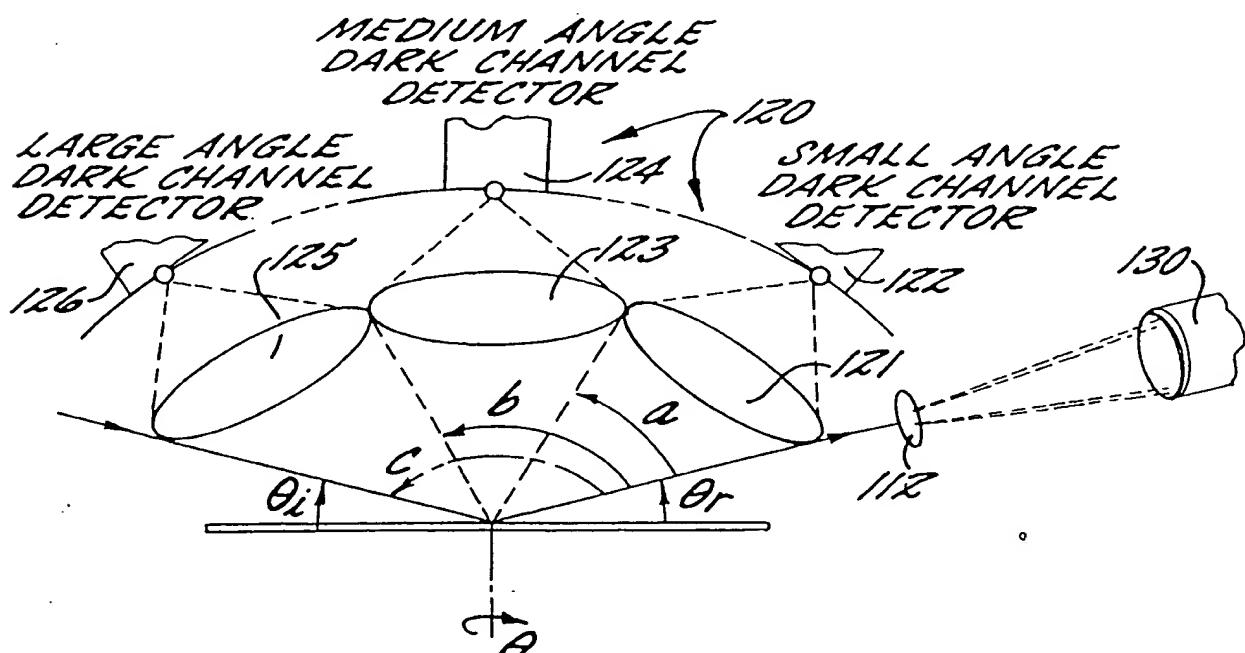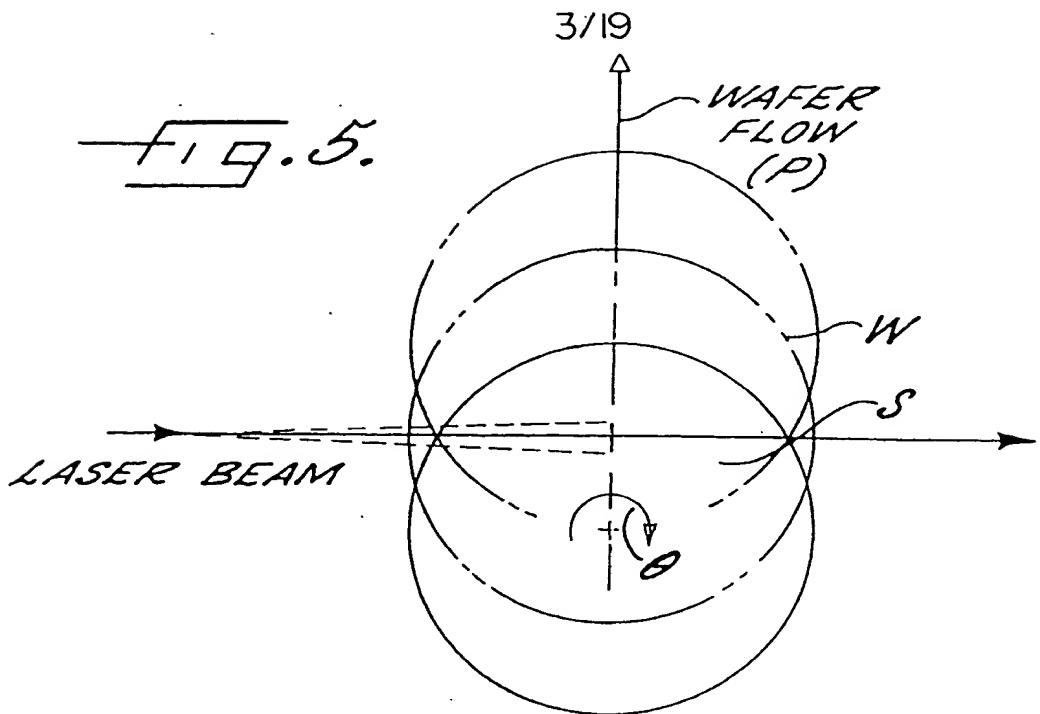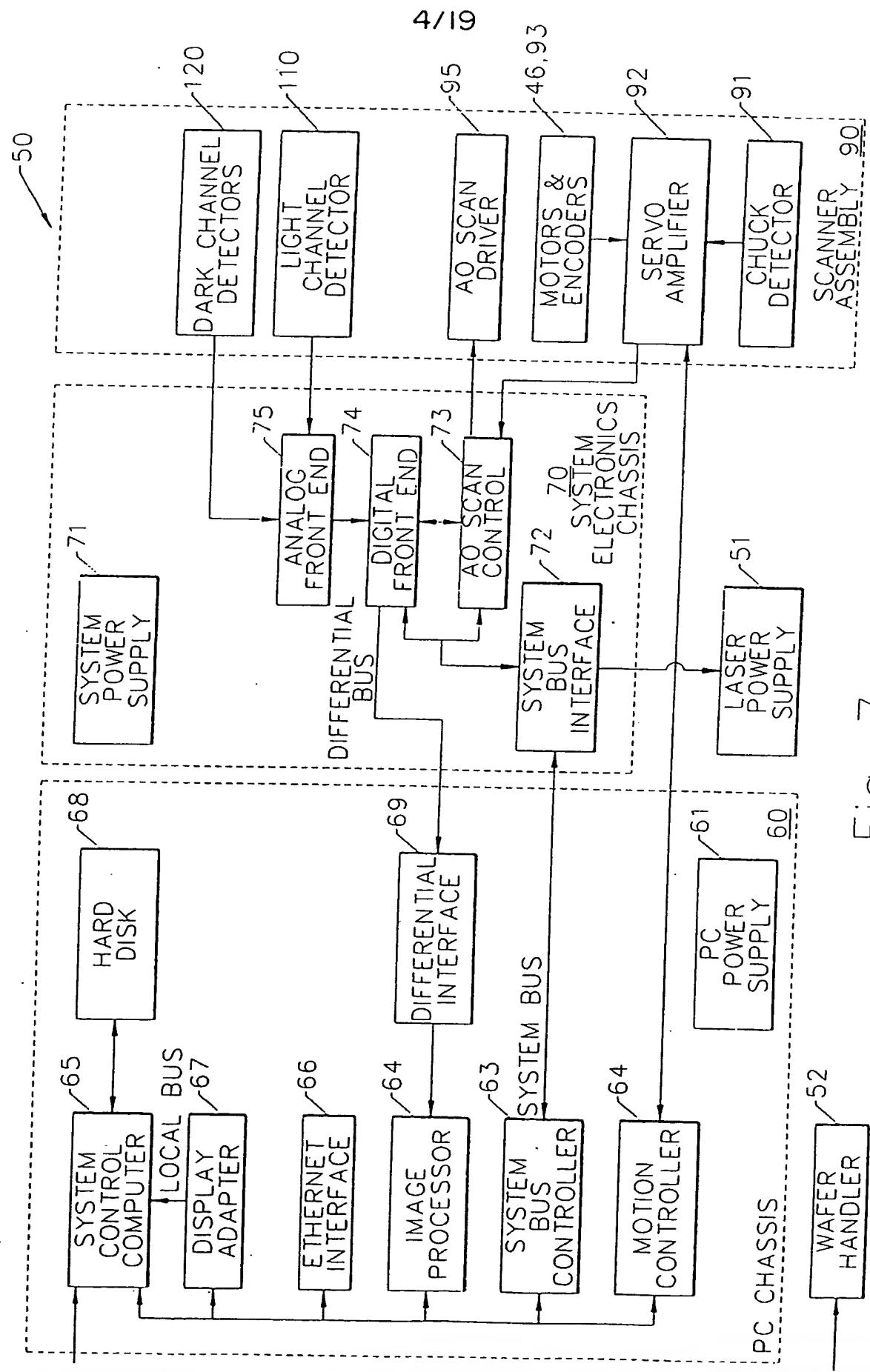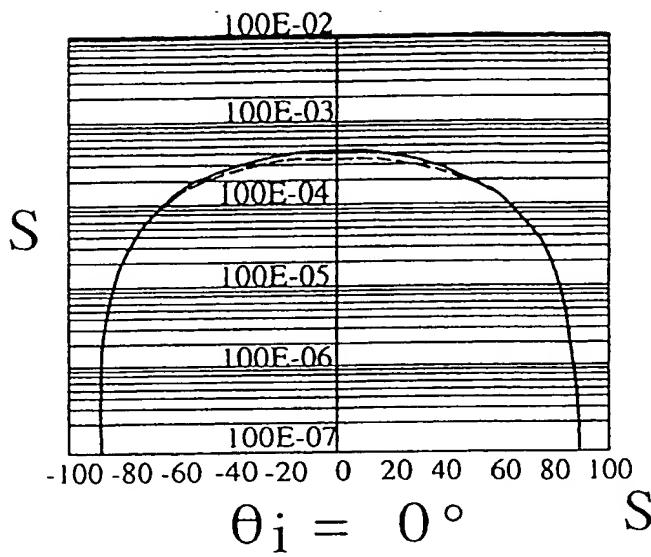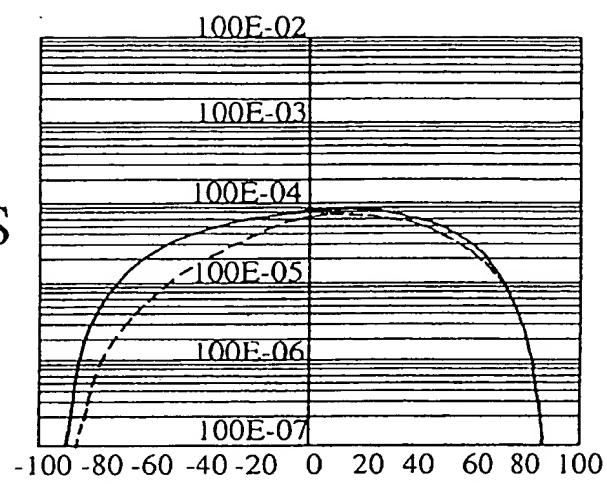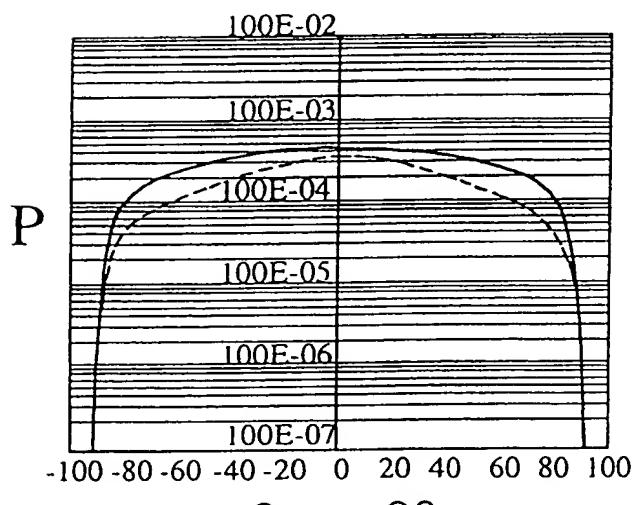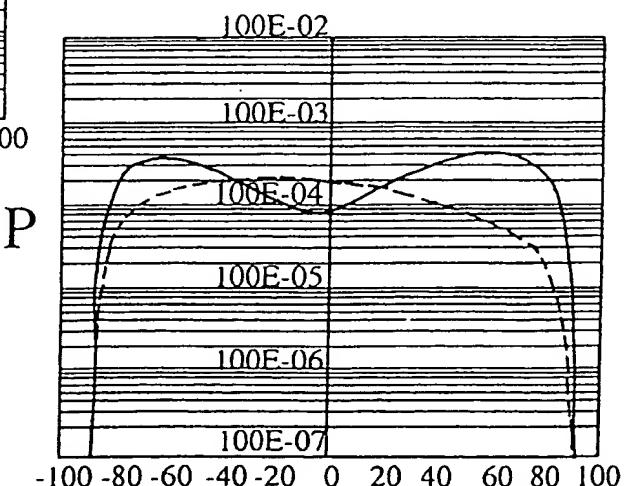
FIG. 8D
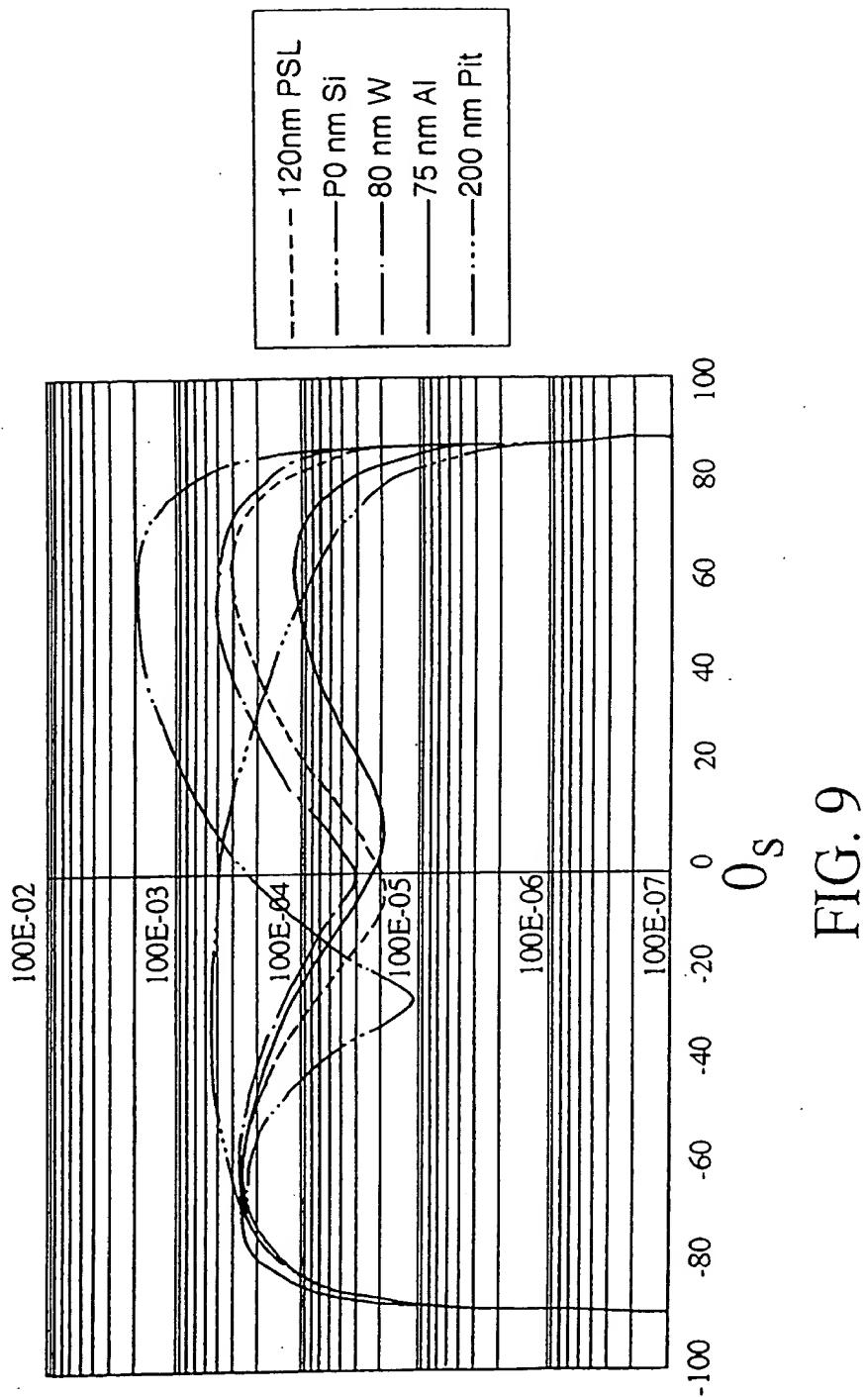
FIG. 9

EXPERIMENTAL RESULTS
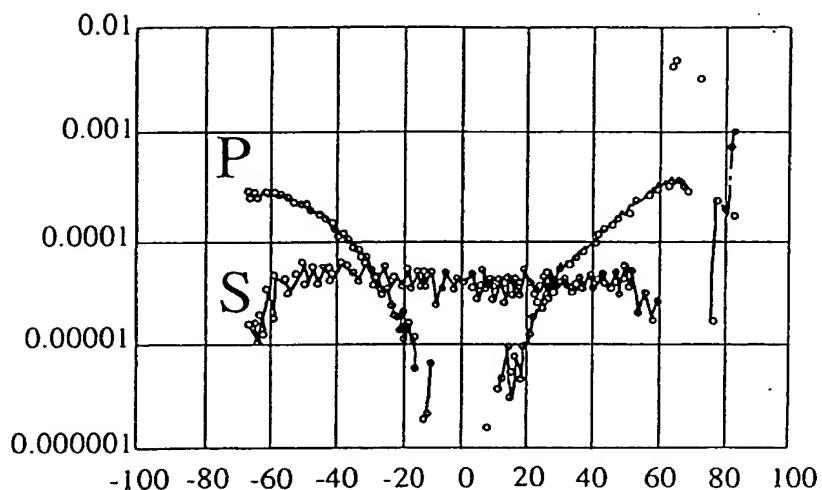
FIG. 10A

MODELED RESULTS



FIG. 10B

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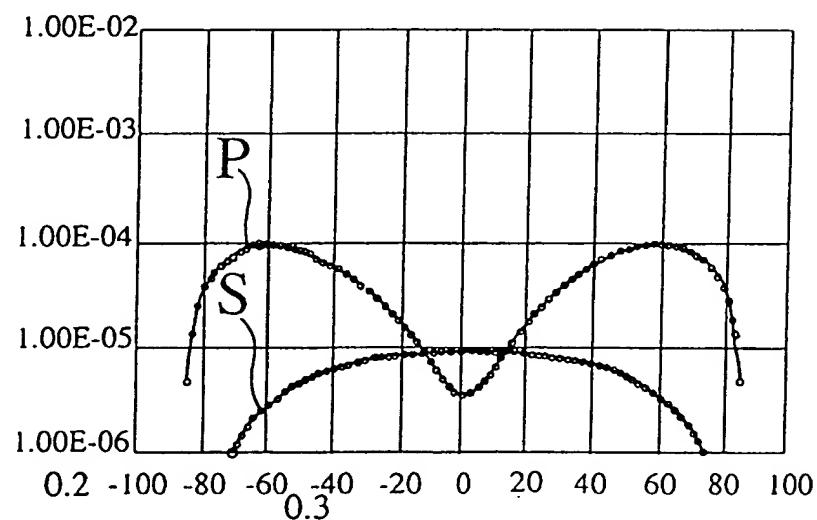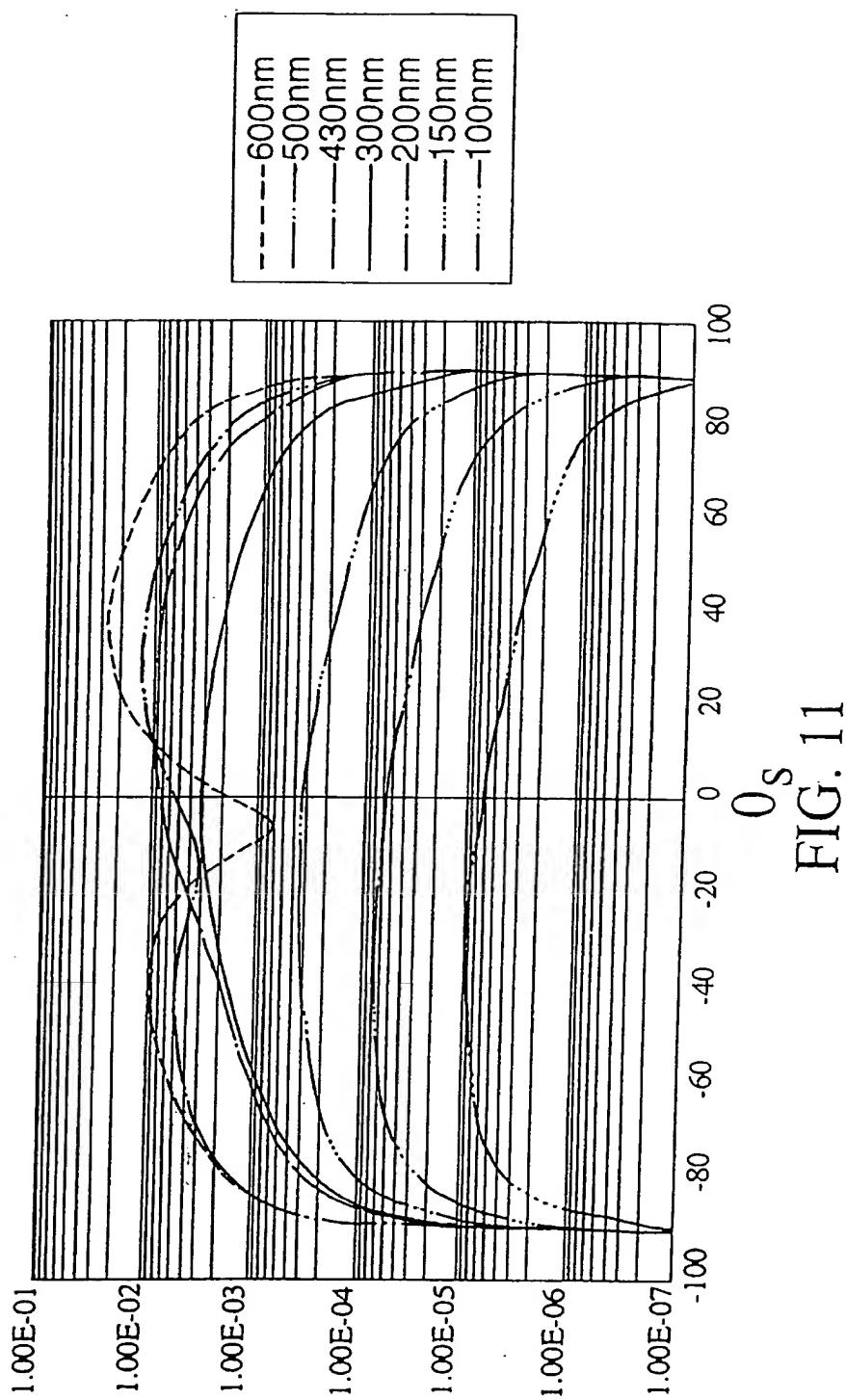
FIG. 11
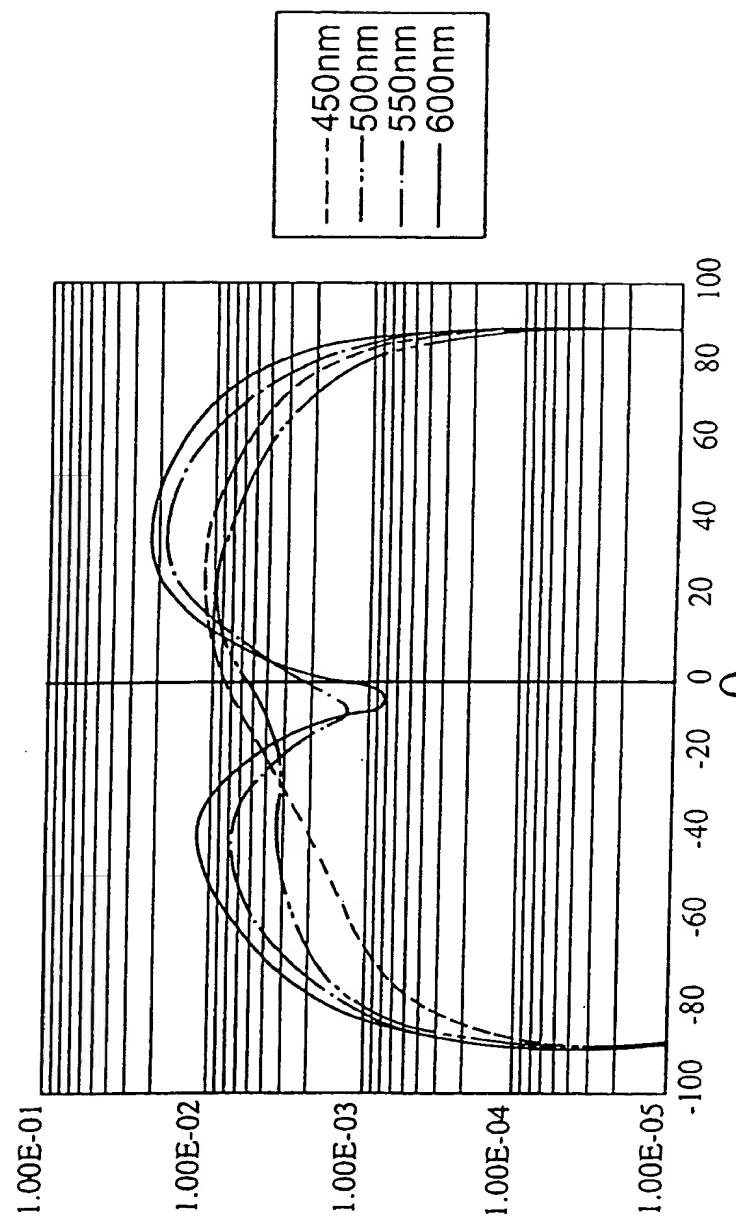
FIG. 12

Model Output: Small COP vs Particles
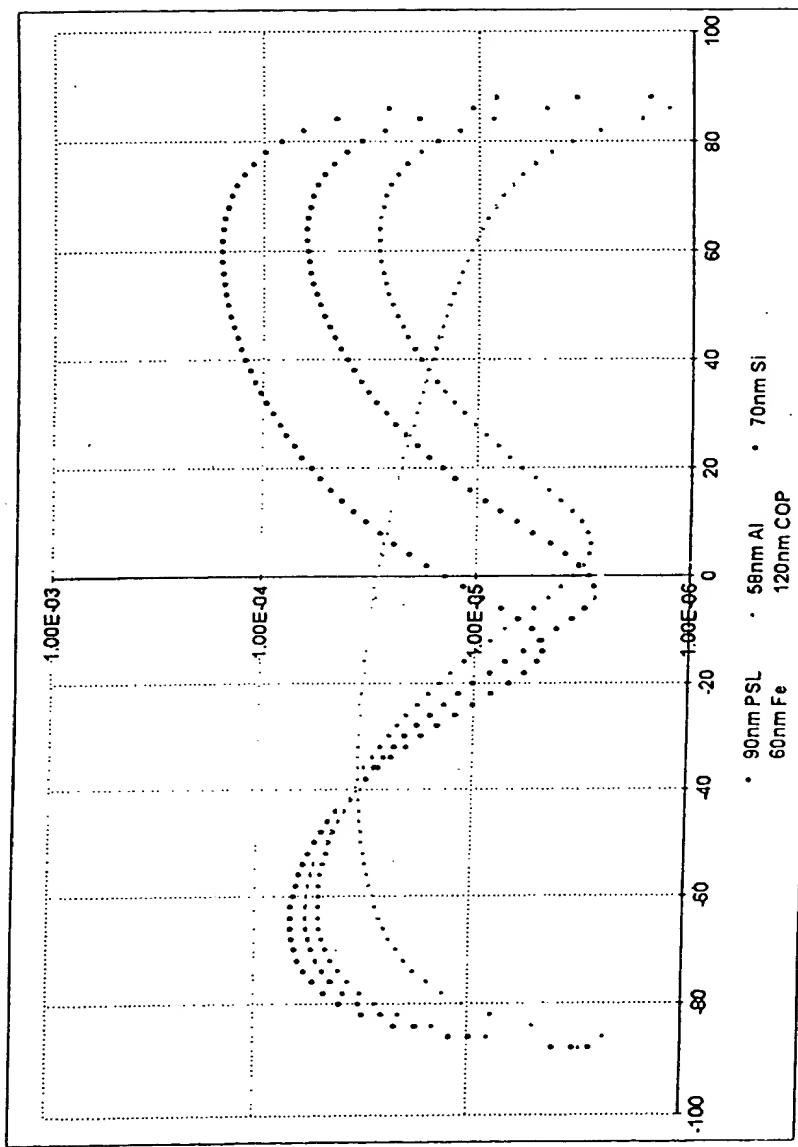
FIG. 13

Model Output: Medium COP vs Particles

- 120nm PSL   • 75nm Al   • 9:nm Si
  80nm Fe   155nm COP
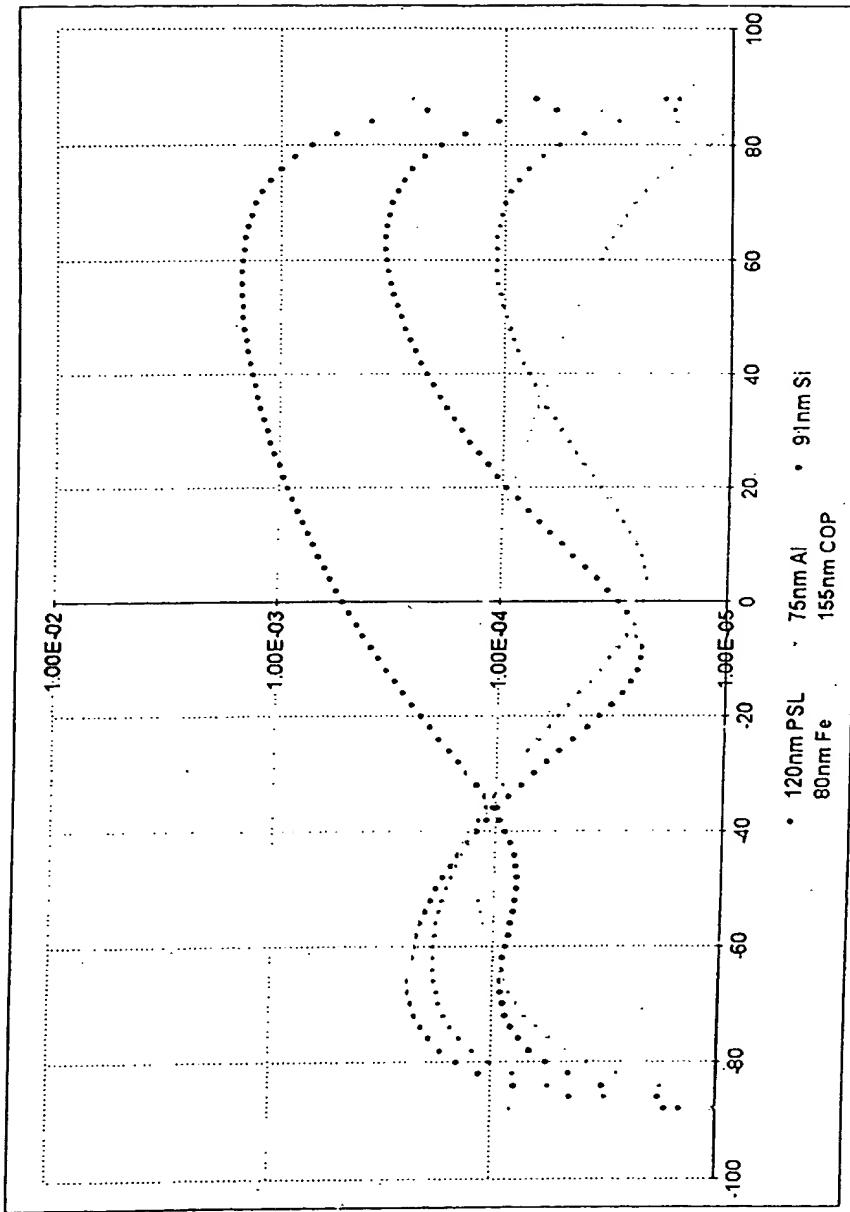
FIG. 14
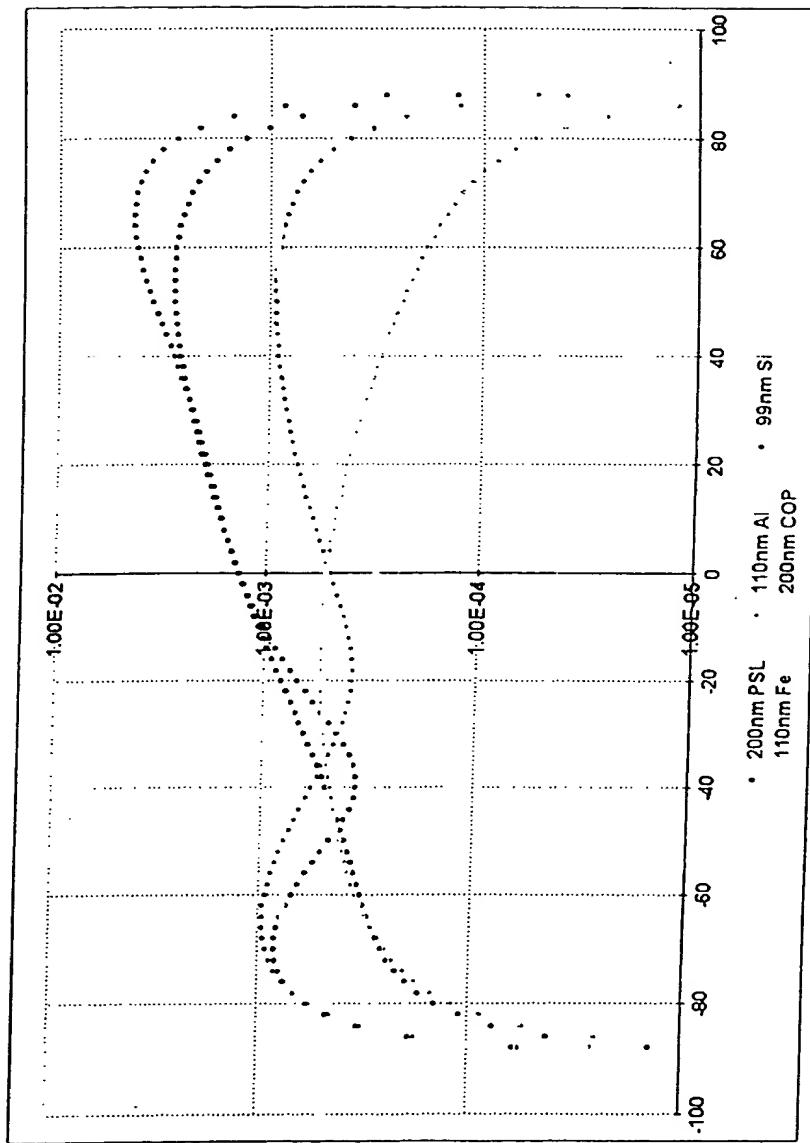
FIG. 15
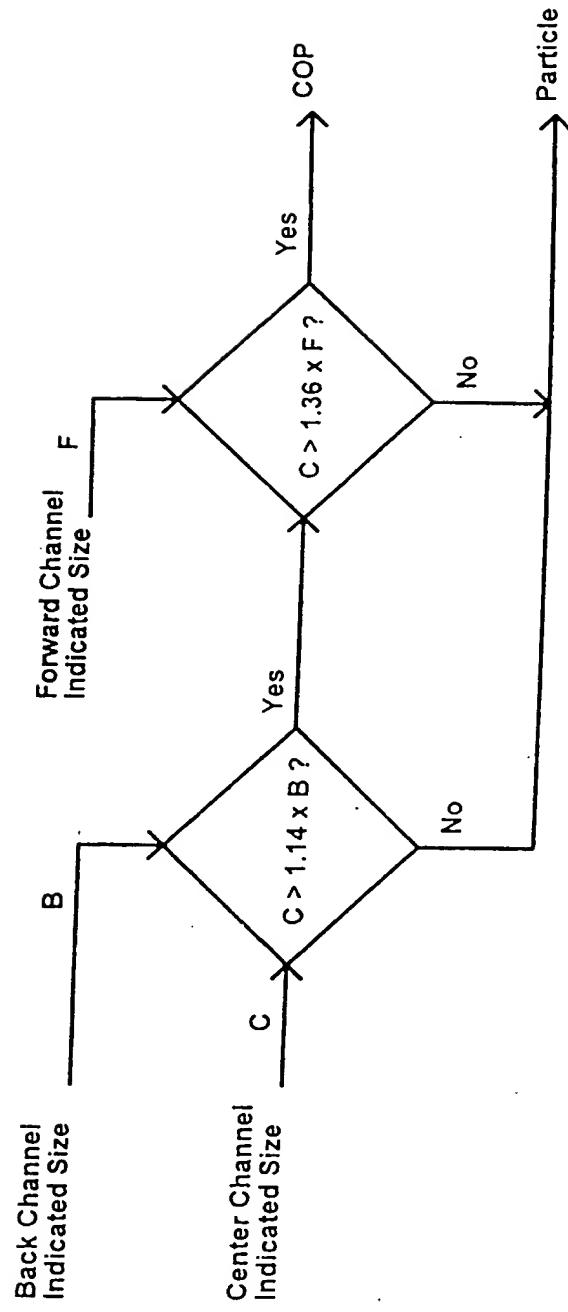
COP Algorithm

FIG. 16

COP ALGORITHM APPLIED TO COPs
MODEL RESULTS
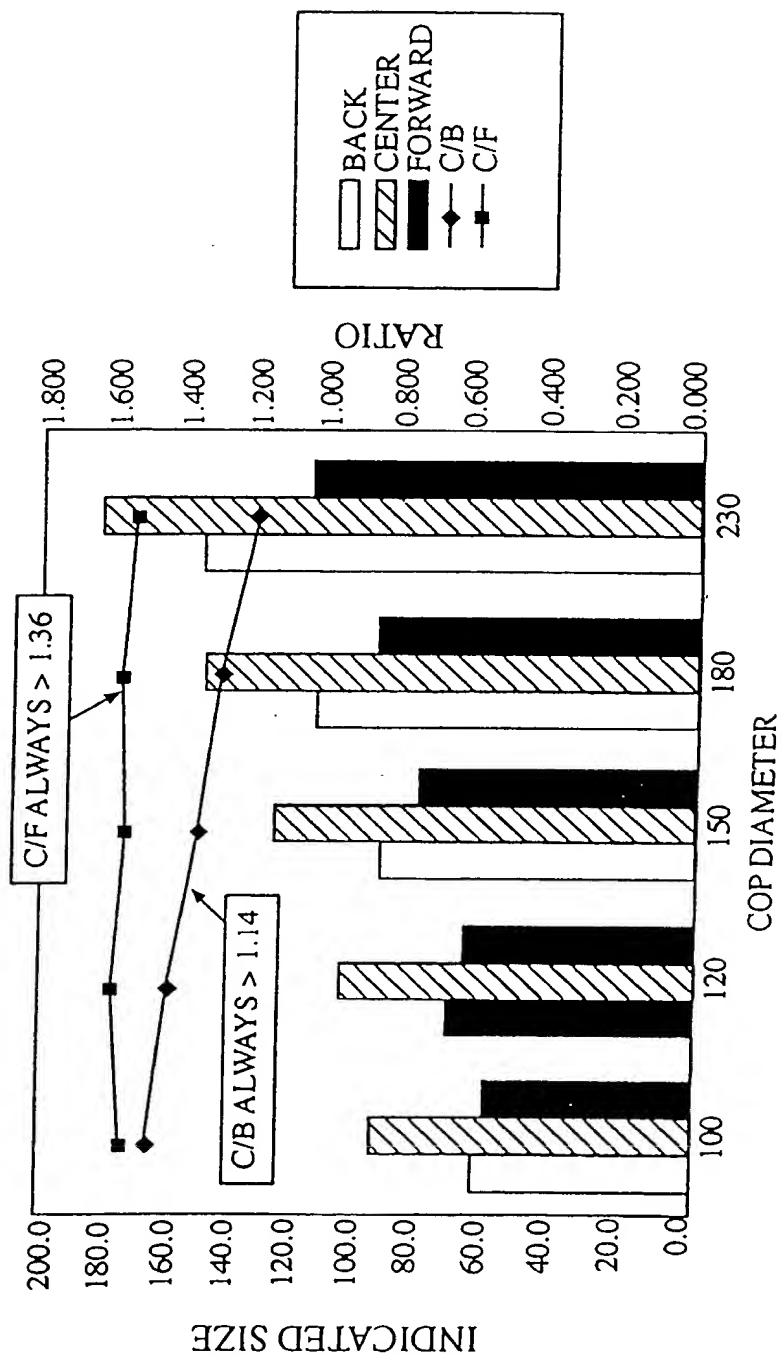
FIG. 17

COP ALGORITHM APPLIED TO ALUMINUM SPHERES
MODEL RESULTS
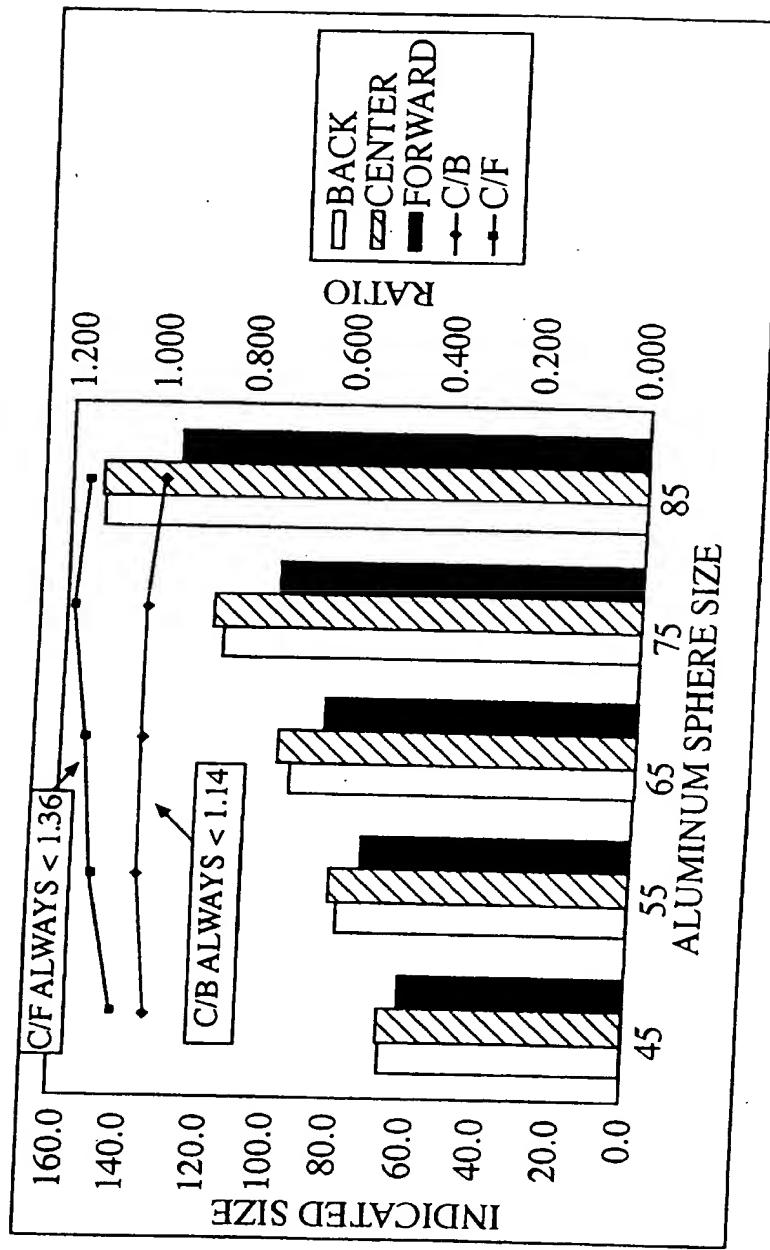
FIG. 18

AWIS PARTICLE MAP OF CZ WAFER

0			
1	0.050-0.100	21	PARTICLE
2	0.100-0.150	25	PARTICLE
3	0.150-0.200	429	PARTICLE
4	0.200-0.250	0	PARTICLE
5	0.250-0.300	1	PARTICLE
6	0.300-0.350	1	PARTICLE
7	0.350-0.400	1	PARTICLE
8	0.400-0.450	0	PARTICLE
9	0.450-0.500	0	PARTICLE
PA			

478 TOTAL PARTICLE

50% @ 0.0997μm

FIG. 19

AWIS COP MAP OF CZ WAFER

O	0	
1	0.050-0.100	0 PARTICLE
2	0.100-0.150	812 PARTICLE
3	0.150-0.200	116 PARTICLE
4	0.200-0.250	6 PARTICLE
5	0.250-0.300	0 PARTICLE
6	0.300-0.350	0 PARTICLE
7	0.350-0.400	0 PARTICLE
8	0.400-0.450	0 PARTICLE
9	0.450-0.500	0 PARTICLE
PA		

934 TOTAL PARTICLE

50% @ 0.1250μm
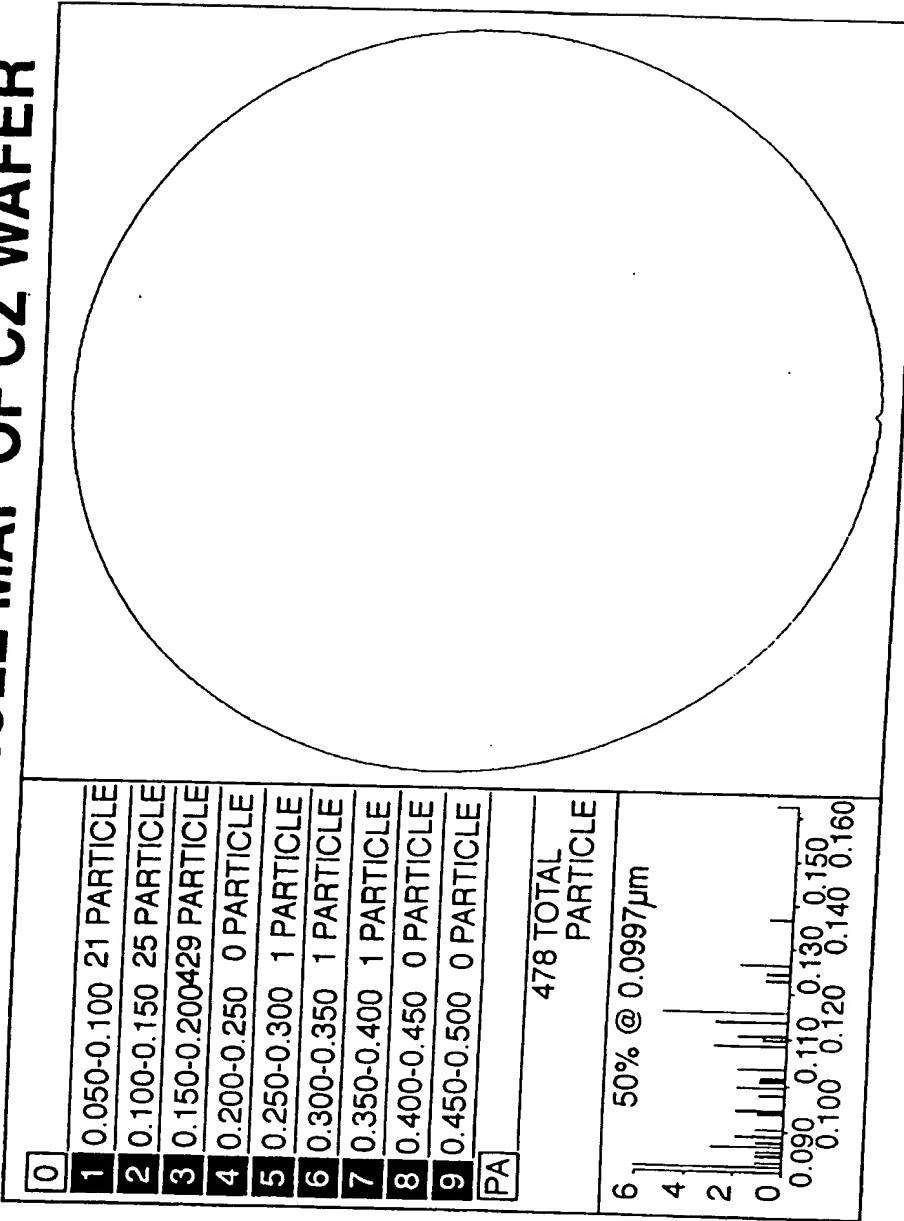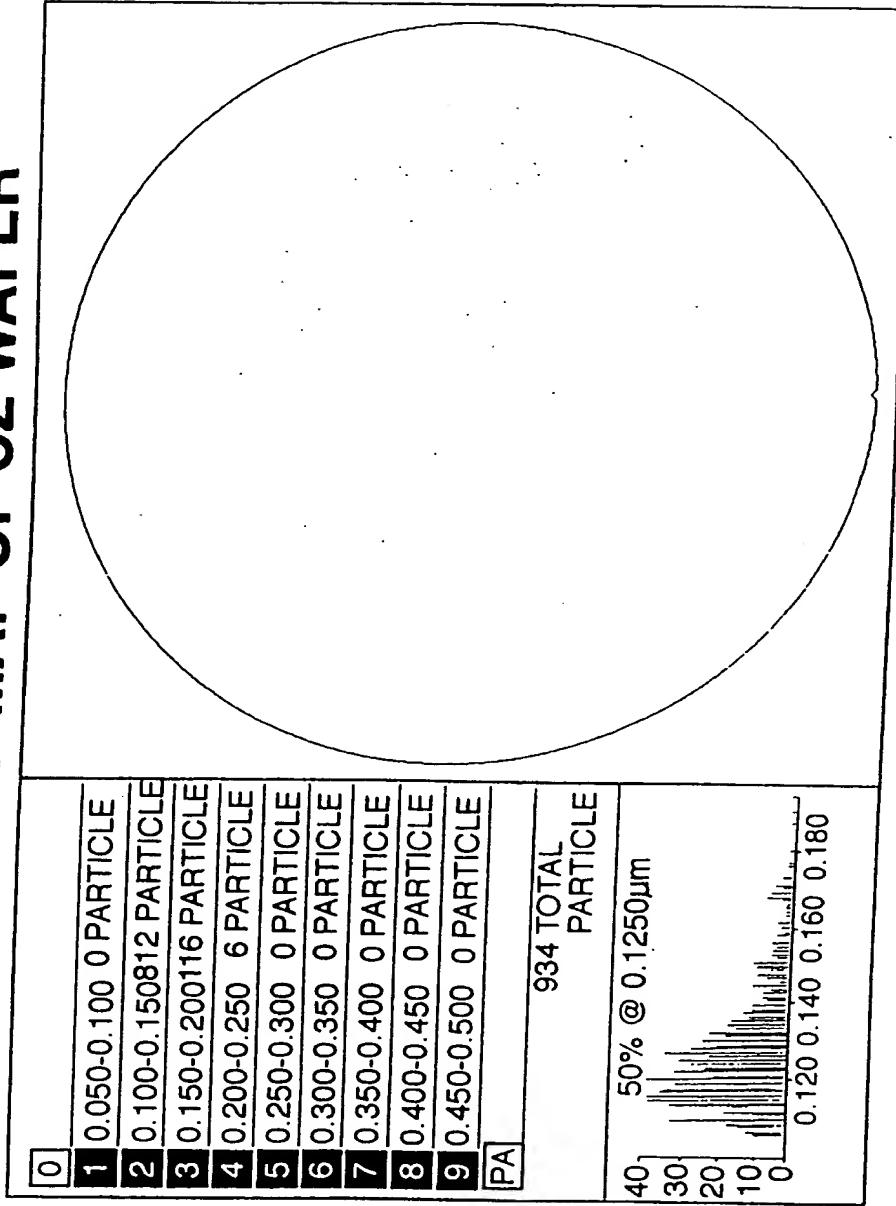
FIG. 20

AWIS PARTICLE MAP OF CZ WAFER
WITH 117nm, 136nm & 157nm

FIG. 21
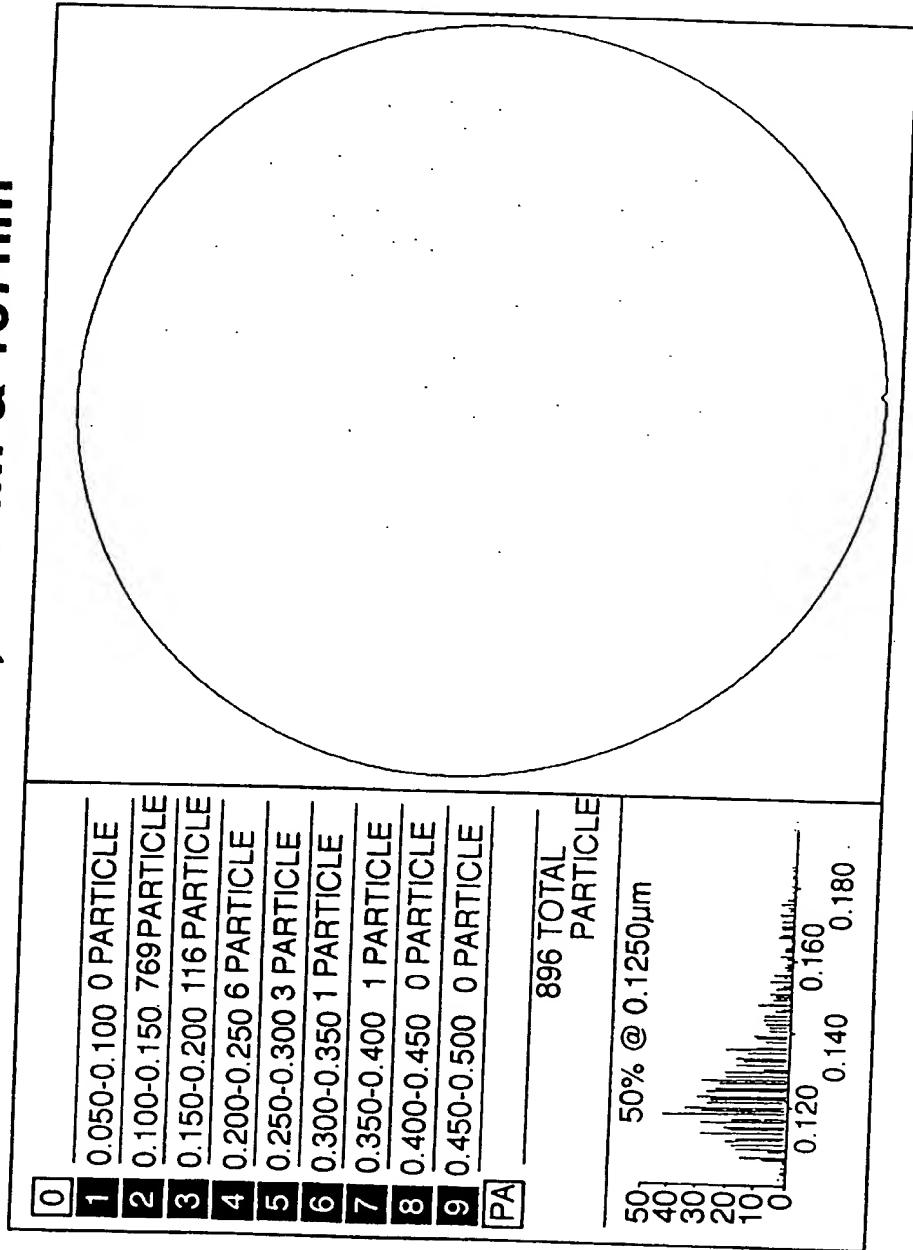
0		
1	0.050-0.100	20 PARTICLE
2	0.100-0.150	2904 PARTICLE
3	0.150-0.200	1764 PARTICLE
4	0.200-0.250	12 PARTICLE
5	0.250-0.300	20 PARTICLE
6	0.300-0.350	10 PARTICLE
7	0.350-0.400	0 PARTICLE
8	0.400-0.450	0 PARTICLE
9	0.450-0.500	0 PARTICLE
PA		

4730 TOTAL PARTICLE

50% @ 0.1347μm

AWIS COP MAP OF CZ WAFER
WITH 117nm, 136nm & 157nm

0	0.050-0.100 0 PARTICLE
1	0.100-0.150 769 PARTICLE
2	0.150-0.200 116 PARTICLE
3	0.200-0.250 6 PARTICLE
4	0.250-0.300 3 PARTICLE
5	0.300-0.350 1 PARTICLE
6	0.350-0.400 1 PARTICLE
7	0.400-0.450 0 PARTICLE
8	0.450-0.500 0 PARTICLE
9	
PA	

896 TOTAL PARTICLE

50% @ 0.1250μm

FIG. 22

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6   G01N21/88

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6   G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96 27786 A (ADE OPTICAL SYST CORP ;CLEMENTI LEE D (US); FOSSEY MICHAEL E (US)) 12 September 1996	1,2,4-9, 12,14
Y		15,24
	see page 3, line 32 - page 9, line 5 see page 10, line 13 - page 11, line 16 see page 13, line 16 - line 25 see page 15, line 33 - page 16, line 3 see page 20, line 13 - line 33 see page 21, line 22 - line 30 see page 24, line 8 - line 27; figures 1,3,6	

Y A	US 5 424 536 A (MORIYA KAZUO) 13 June 1995	15,24 1
	see column 1, line 42 - column 2, line 23 see column 4, line 15 - line 49; figure 1	
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[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
24 March 1998	8. 04. 98.

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